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BASF Corporation
Wyandotte, Michigan

Interim Measures Design Work Plan — Sediments

BASF North Works

August 2010

BASF

The Chemical Company

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Subject:
Draft Interim Measures Design Work Plan – Sediments
BASF North Works, Wyandotte, Michigan

Dear Mr. Thomas:

Enclosed is the draft Interim Measures Design Work Plan (IMDWP) for sediments adjacent to North Works for Federal and State review.

This draft IDMWP was prepared to satisfy the agreement with USEPA as an outcome of the dispute resolution process per USEPA's June 23, 2010 letter. With this submittal, BASF does not relinquish a view that the remedy and/or scope of the remedy may be unnecessary or inappropriate from a risk management perspective; however, the approach described here is presented in the spirit of cooperation.

During the IMDWP preparation meeting in Chicago on July 29th, USEPA requested certain additional information be provided. As indicated during that meeting, this draft IMDWP was substantially complete then, given the relatively short schedule available for its preparation and completion. A number of the requested items are addressed and included in this IMDWP. The others are in preparation by ARCADIS, and when completed, will be provided to USEPA under separate cover.

Respectfully,

MJE on behalf of Mike Gerdenich

Mike Gerdenich

Copies: Brian Diepeveen (BASF), Rich Conforti (MDNRE), Amy Mucha (GLNPO), Mike Erickson (ARCADIS)

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Interim Measures Design Work Plan - Sediments

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AOC	Administrative Order of Consent
ATSDR	Agency for Toxic Substances and Disease Registry
BASF	BASF Corporation
BAZ	bioavailable zone
BMPs	best management practices
BSLs	background screening levels
CAD	confined aquatic disposal cell
CDF	confined disposal facility
COCs	constituents of concern
CSOs	combined storm sewer outfalls
CU	cap unit
cy	cubic yards
EIFAC	European Inland Fish Advisory Commission
GLEC	Great Lakes Environmental Center
GROs	General Response Options
HASP	Health and Safety Plan
IM	interim measure
IMDWP	Interim Measure Design Work Plan
IMWP	Interim Measures Work Plan
MDEQ	Michigan Department of Environmental Quality
MDNRE	Michigan Department of Natural Resources and Environment
MNR	monitored natural recovery
O&M	Operation and Maintenance
PCB	polychlorinated biphenyl
PAH	polycyclic aromatic hydrocarbon
ppm	parts per million
QAPP	Quality Assurance Project Plan
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RTK-DGPS	Real-Time Kinematic Digital GPS
RU	removal unit

Site	BASF North Works Site
SPI	Sediment Profile Imaging
STP	sewage treatment plant
SVOCs	semivolatile organic compounds
TCLP	Toxicity Characteristic Leaching Procedure
TOC	total organic carbon
USACE	United States Army Corp of Engineers
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds
WWTP	wastewater treatment plant
XRD	X-ray diffraction
XRF	X-ray fluorescence
4,4'-DDE	4,4'- Dichlorodiphenyldichloroethylene

1. Introduction

An Administrative Order on Consent (AOC) identifies activities to be completed in accordance with the Resource Conservation and Recovery Act (RCRA) at the BASF Corporation (BASF) North Works property (the Site) located in Wyandotte, Michigan (United States Environmental Protection Agency [USEPA] 1994a).

Presently, the Site is an active manufacturing facility that produces a variety of products. The property has been utilized for various manufacturing purposes for more than a century. The Site encompasses approximately 230 acres along approximately 1.1 miles of the shoreline of the Trenton Channel of the Detroit River in the City of Wyandotte, Michigan (Figure 1-1).

This *Interim Measures Design Work Plan* (IMDWP) has been prepared by BASF to resolve a dispute with USEPA concerning a May 18, 2010 demand letter to BASF that stated a requirement to implement immediately (to be completed in 2010) a presumptive remedy (sediment removal) to address USEPA's presumption of bulk sediment pH-driven toxicity to benthic organisms. BASF maintains that USEPA's demands are inappropriate for multiple reasons, including: benthic toxicity has been shown to be the result of many different types of chemicals from many sources; upstream sources of contamination certainly continue; the available data show that there are no pH exceedances of water quality criteria in the Detroit River at the Site and that pore water pH levels are much lower than those detected in bulk sediment; the ecology at the site shows functioning habitat for plant, fish, and benthic species; there is adequate time available to properly study and select an appropriate risk management activity; and importantly, that additional data collection to understand what, if any, actual risks are posed by the pH conditions in bulk sediment should have been collected.

BASF proposed data collection to address key remaining questions in January 2010 before receiving USEPA's demand letter in May 2010 for the presumptive removal action. This IDMWP was prepared to satisfy agreements with USEPA as an outcome of the dispute resolution process per USEPA's June 23, 2010 letter, and includes data collection to help define if and what risk management activities are appropriate at the Site, but also includes a proposed remedy that, in the spirit of cooperation to move forward, is based on USEPA statements about what type of minimum remedy would be required for a reviewable submittal (one involving "significant removal"). However, in submitting this draft IMDWP for Federal and State review, BASF does not relinquish a view that the remedy and/or scope of the remedy may be unnecessary or inappropriate from a risk management perspective. BASF maintains additional data collection is needed to identify what, if any, actions are appropriate, particularly with regards to consideration of actual levels of pH exposure to organisms, and the degree of toxicity represented by pH compared to other stressors present in the sediment, as well as other ongoing contamination present from upstream and recontamination potential. Addressing ongoing sources is USEPA's Sediment Management Principle No. 1, and management of sediments from a risk basis, without a presumptive remedy, are cornerstones of USEPA's Contaminated Sediment Remediation Guidance (USEPA 2005). BASF believes the current basis for the proposed remedy may be overly conservative with respect to underlying assumptions regarding pH exposure levels, as well as the scope of remediation/sediment quality improvements that may be sustainable. For example, one of the data gaps should evaluate toxicity issues more closely as conclusions regarding the condition of benthic habitat and a remedy decision should not be based on one toxicity test. This testing should be verifiable and reproducible.

1.1 Background

In response to and in cooperation with agency requests, investigative work related to Site sediments began in 2006 and has continued since. In an undated letter received by BASF on June 15, 2006, USEPA communicated the following requests to BASF related to completion of the RCRA Corrective Measures Study for the Site:

- A "map of navigational channel that may establish whether the area adjacent to the river is a depositional area"; and

- "An evaluation of sediments that first verifies the presence/absence of sediment and if present, collect samples adjacent to the site as well as upstream and downstream to characterize sediment quality relative to background. Sediments would be analyzed for constituents including mercury."

To fulfill the requirements set forth by USEPA, BASF provided a bathymetric map of the Trenton Channel and a summary of other relevant hydrodynamic and sediment quality information pertaining to industrial facilities and municipal storm sewer outfalls, and flow patterns into the Trenton Channel from upstream areas (BBL 2006). This information, prepared for BASF by Blasland, Bouck & Lee, Inc. (now ARCADIS), indicated that sediments in this part of the Trenton Channel would likely be limited to areas along the channel margins, and would reflect a continuum of impacts extending downstream into the Trenton Channel from numerous upstream sources.

On July 26, 2007, USEPA approved the *Sediment Probing Study Data Quality Objectives and Work Scope* (ARCADIS BBL 2007a) submitted by BASF for assessing the presence or absence of sediments adjacent to the Site. BASF completed the physical investigation of sediments adjacent to the Site in August 2007 and prepared a report presenting the data that was submitted to the USEPA in September 2007 (ARCADIS BBL 2007b). Simultaneously, the Michigan Department of Environmental Quality (MDEQ; now Michigan Department of Natural Resources and Environment [MDNRE]) completed a sediment assessment sampling program adjacent to the Site (A. Ostaszewski pers. comm. 2008). The sample analysis results were provided to BASF. USEPA and MDNRE expressed a view that the available data were inadequate to reach conclusions regarding comparisons of sediments adjacent to and upstream of the Site, and requested additional characterization of sediments.

In response, BASF prepared the *Phase II Sediment Investigation: Core Collection and Analysis Work Plan* (ARCADIS 2008a) providing for additional characterization of the nature of Site sediment relative to background or upstream concentrations. This work plan was approved by USEPA and field work was conducted in 2008. In March 2009, results were reported to USEPA in the *Phase II Sediment Investigation Data Summary Report* (ARCADIS 2009a). The report included a statistical evaluation of along-site sediments compared to upstream sediments and most constituents were detected at concentrations statistically comparable to levels present in upstream samples. Locally elevated levels of some constituents were observed, including bulk sediment pH values.

BASF proposed and then discussed with USEPA several data collection activities to address data needs, as necessary, to better understand the extent of elevated bulk sediment pH levels adjacent to the Site and the potential risks to the environment posed by these sediments; as well as to collect data with utility for evaluation and design of potential remedial measures, if needed. An updated schedule to collect additional data was also provided to USEPA.

Subsequent to BASF's proposal, USEPA requested that BASF prepare an Interim Measures Work Plan (IMWP) to address elevated bulk sediment pH levels in certain sediments adjacent to the Site (USEPA 2009); the *Sediment Characterization/ Remedial Evaluation Interim Measures Work Plan* (ARCADIS 2009b) included hydrographic survey, in-situ sediment profile imagery, benthic community assessment, additional sediment characterization sampling, and pore water sampling. The IMWP investigations were completed in 2009, and interim results were shared after each major sampling task in a series of teleconference meetings with USEPA to review and discuss proposed sample locations for subsequent tasks. The fourth data share meeting took place in Chicago in January 2009 and included a summary and overview of all results collected to date, as well as additional data collection recommendations by BASF prior to design activities. In March 2010, a data package was submitted to USEPA which summarized all the data collected during the 2009 Interim Measures investigation (ARCADIS 2010).

A May 18, 2010 letter received by BASF from USEPA (USEPA 2010a) directed BASF to submit within 30 days an *Interim Measure Design Work Plan* (IMDWP) for sediment removal during the 2010 calendar year. BASF invoked the dispute resolution process provided for by the AOC (USEPA 1994a) to resolve a dispute concerning certain aspects of the May 18, 2010 letter. Following dispute resolution meetings, USEPA issued a letter to BASF on June 23, 2010 (USEPA 2010b) modifying the directions stated in the May 18, 2010 letter (USEPA 2010a), specifically withdrawing the requirement for BASF to submit an IMDWP for sediment removal for implementation during the 2010 calendar year and instead directing BASF to submit an IMDWP that includes:

a) "an alternatives evaluation, with BASF's recommended remedy;

b) conceptual drawings illustrating the recommended remedy;

c) identification of data gaps (i.e., data needed to complete the design); and

d) an estimate of the time required to implement the remedy (i.e., the amount of time, from start to finish, needed for the project)."

This IMDWP has been prepared to satisfy those requirements.

1.2 Site Description

The Site (Figure 1-1) is an active industrial complex situated on approximately 230 acres in Wyandotte, Michigan, adjacent to the federally maintained Trenton Channel of the Detroit River and downstream of the industrial centers and the urban center of Detroit. The Site is bounded on the east by the Detroit River, on the west by Biddle Avenue and by property lines to the north (Perry Street) and south (Mulberry Street). The Site shoreline is approximately 1.1 miles in length and is entirely armored by steel sheet pile bulkhead, concrete bulkhead, or heavy rip-rap. Water depths range from 3.2 feet up to 21 feet along the shoreline.

1.3 Site History

The Site location was originally a section of Detroit River marsh prior to European habitation (Woodward-Clyde 1994). Development as a manufacturing facility began with drainage and placement of fill materials. A history of the industrial processes occurring at the Site is included in Section 2.2 of the RCRA Facility Investigation (RFI) Report (QST Environmental 1999) while details of filling, waste handling, and disposal methods are found in Section 3 of the RFI Report (QST Environmental 1999).

Pollution of the Detroit River and Trenton Channel that has occurred over the past century or more can be attributed to many diverse point and diffuse industrial and municipal sources throughout the history of intense industrialization and urbanization of the area. The locations of many such sources along the Detroit River and Trenton Channel have been documented by others.

A number of spills have occurred on the Detroit and Rouge Rivers, including a significant spill in April 2002, when 100,000 gallons of oil spilled in the Rouge River resulting in a cleanup effort on both the Rouge and Detroit Rivers.

The industrial history and sources of contamination to the Detroit River are important with respect to potential for ongoing sources and transport that may continue to sustain legacy impairment of sediments to some extent.

1.4 Data Used in Interim Measures Design Work Plan Development

Several studies of the Detroit River and Trenton Channel have yielded data upstream, downstream, and adjacent to the Site. The data that provides the basis for this IMDWP were collected pursuant to USEPA-approved work plans as part of the RCRA activities. The data collection activities and types of data are summarized below:

- 2007 sediment probing investigation (ARCADIS BBL 2007a) provided sediment thickness data along transects the entire length of the Site.
- Phase II Sediment Characterization Investigation (ARCADIS 2008a) provided analytical data, field parameters (including bulk sediment pH) and stratigraphy information from sediment cores upstream of and adjacent to the Site.
- 2009 Sediment Characterization/Remedial Evaluation (ARCADIS 2009b) provided the following:

- Hydrographic survey adjacent to the Site including multi-beam sonar bathymetry, side-scan sonar mapping of the sediment surface features and texture, and magnetometer readings.

- Additional sediment core visual observation, field bulk sediment pH measurement and chemical analysis results.

- Sediment geochemical composition data from X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) analyses of select samples adjacent to the Site.

- Sediment Profile Imaging (SPI) at locations adjacent to the Site and upstream.

- Benthic community assemblage data from locations adjacent to the Site and upstream.

- Near-bottom surface water pH and pore water pH readings adjacent to the Site using the Trident probe.

- In conjunction with the 2009 investigation activities by BASF, USEPA contractors conducted laboratory bioassays which provided bioassay results for two test species, and associated jar test overlying water pH and bulk sediment pH data (Great Lakes Environmental Center [GLEC] 2009).

1.5 Work Plan Purpose and Organization

This IMDWP has been prepared to satisfy the requirements of the June 23, 2010 USEPA letter (USEPA 2010b) by evaluating alternatives and providing conceptual drawings illustrating the recommended remedy, identify data gaps, and estimate the time required to implement the remedy.

The remainder of this document is organized as follows:

- Section 2 – Conceptual Site Model summarizes the results of investigational efforts and characterizes the contamination at the Site.

- Section 3 – Interim Measures Objectives and Basis utilizes data discussed in Section 2 to identify project drivers and cleanup goals, media and areas to be remediated, volume of material to be remediated, and the objectives of the interim measure (IM).

- Section 4 – Evaluation of Interim Measure Alternatives screens and evaluates potential remedial technologies are according to defined criteria to determine which alternative best accomplishes the objectives of the IM.

- Section 5 – Interim Measure Design Data Needs identifies and describes studies that need to be performed and data that need to be collected before a formal design work plan of the selected IM can be completed.

- Section 6 - Basis of Design describes the major elements of the proposed work plan for implementation of the selected IM. These elements include access to the work areas, work to be performed, resuspension controls, and construction of the selected IM.

- Section 7 – Conceptual Design Components describes the concept of how the selected technology will accomplish the goals of the IM. Included is a description of how each element of construction serves to achieve the objectives of the IM.

- Section 8 – Required Permits, identifies potential permits needed to construct the selected IM.

- Section 9 – Key Submittals and Schedule discusses project organization including lines of authority; project schedule including major assumptions, potential delays, and major milestones; and potential public involvement.

- Section 10 - References lists the references cited in this IMDWP.

2. Conceptual Site Model

2.1 Site Within Detroit River Area of Concern

According to the 1996 Detroit River Remedial Action Plan (RAP) Report (Detroit River RAP Working Group 1996), the status of Detroit River sediments in 1996 was defined as "moderately to severely contaminated". In a 2001 update report to the Detroit River RAP (Detroit River RAP Working Group 2001), historical trends indicated that effects to Impairments of Beneficial Use had decreased significantly and generally throughout the 1990s there had been a continued gradual decrease of additional harm to the river. Significant upstream contaminant sources and impacted sediment inventories have been documented (Beak 1993, Detroit River RAP Working Group 1996, MDEQ 1997, USEPA 2009).

A number of industrial and municipal dischargers are located along the Detroit River as well as combined storm sewer outfalls (CSOs). Additionally, the City of Detroit wastewater treatment plant (WWTP) discharges effluent near the mouth of the Rouge River and Zug Island with a maximum monthly discharge rate of 830 million gallons per day (MGD). A dye study conducted by Environmental Science & Engineering, Inc. for the Detroit Water and Sewerage Department shows the Detroit WWTP plume, as well as plumes from other sources in the vicinity of Zug Island, flows primarily into the Trenton Channel (Upper Great Lakes Connecting Channels Study 1988).

Other sources of potential contamination, such as marinas and fuel stations in close proximity to the river, are located upstream of the Site. These upstream sources and contaminated sediment inventories collectively act as ongoing sources of contamination typical of any industrialized urban watershed. Among the upstream sources are direct outfalls to the Detroit River, direct outfalls to major tributaries, indirect CSOs, leachate and runoff from landfill or dredge spoil areas, atmospheric deposition of exhaust and stack emissions, and urban surface runoff (QST Environmental 1999). Although the principal sources of direct water pollution are reportedly the sewage treatment plant (STP) outfalls and CSOs, there is evidence that significant portions of industrial wastes are discharged to the river via the municipal STPs (Comba et al. 1985).

Contaminated dredged material from both the Trenton Channel and the Rouge River has historically been placed on Grassy Island and Mud Island, both of which are upstream of the Site. Grassy Island, in particular, contains polychlorinated biphenyls

(PCBs), polycyclic aromatic hydrocarbon (PAHs), and metals (Agency for Toxic Substances and Disease Registry [ATSDR] 2007).

2.2 Summary of Available Sediment Analytical and Bulk Sediment pH Data

Investigations completed adjacent to the Site were described previously in Section 1. These investigations have resulted in a sediment dataset that includes 23 inorganics (including total cyanide and the Michigan 10 metals), 17 volatile organic compounds (VOCs), 14 semivolatile organic compounds (SVOCs), 16 PAHs, three PCB Aroclors (1248, 1254, and 1260), one pesticide (4,4'- Dichlorodiphenyldichloroethylene [4,4'-DDE]), and conventional field parameters (bulk sediment pH, total organic carbon [TOC], sulfide, and grain size). Additional field parameters were measured in a subset of samples used for benthic community assessments and toxicity testing, including chloride, ammonia, dissolved oxygen, and water pH.

Because the Site is located downstream of an urban industrial setting with many historical and ongoing sources, surface sediment quality adjacent to the Site can be assumed to be approximately the same as upstream conditions if there are no Site-related sources. An IM should be designed to achieve a realistic goal relative to upstream conditions. The project footprint (discussed in Section 3 and in detail in Appendix A) is guided by the magnitude and spatial extent of constituents that exhibit concentrations elevated above upstream levels and which may be local stressors to the aquatic ecosystem based on associations with variance in benthic community assessment and toxicity endpoints. Many physical and geochemical factors may contribute to the variability in concentrations observed throughout the study area. Therefore, comparisons were performed using methods designed to identify differences in concentrations given the observed variability, including point-by-point screening to upper bound statistics (i.e., background screening levels [BSLs]), hypothesis testing, and bivariate geochemical regression plots. As summarized in the *Phase II Sediment Investigation: Data Summary Report* (ARCADIS 2009a), concentrations for 21 of 58 constituents were below applicable BSLs in all Site samples. For these constituents, concentrations adjacent to the Site are within plausible range observed upstream and, therefore would not be drivers for IM. However, for constituents like bulk sediment pH and phenol that do exhibit higher concentrations adjacent to the Site (based on both exceedances of the BSL and statistically significant differences in the overall distribution), the project footprint can be expect to yield post-remediation conditions (i.e., after recontamination) that are similar to upstream concentrations.

Bulk sediment pH measurements were collected during both the 2008 and 2009 sediment investigations. However, bulk sediment pH may be less representative of exposure conditions than pore water or surface water pH. A water quality criterion of pH = 9.0 (for surface water) has been adopted for Michigan (MDEQ 2006). Site-specific information was used to estimate the association between water pH and bulk sediment pH at each upstream and Site sampling location. The 2009 investigation included collection of pore water and surface water (via the Trident probe) and subsequent pH measurements. Although Trident probe measurements provide a direct measure of pore water conditions, they were conducted at a different time, and not in the precise location of the sediment core data due to limits on reoccupying locations in the field. The surface water pH and bulk sediment pH from USEPA's bioassay results, in which surface sediment samples were placed in a jar with overlying water and allowed to stand for a period of 10 days, provide direct point-to-point water and sediment pH comparisons.

Table 2-1 compares the pH measurements for the surface sediment to pore water and surface water measured with the Trident Probe and overlying water from bench-top bioassay experiments performed by USEPA. The bulk surface sediment pH ranged in the subset of samples from 9.3 standard units[1] to 11.5 with a mean of 10, which is comparable to the full dataset for which bulk surface sediment pH ranged from 7.4 to 11.7 with an average pH of 9.8.

Table 2-1 – Sediment, Pore water, Surface Water pH Comparison

pH Measurements	Bulk Surface Sediment	Trident Probe Surface Water	Trident Probe Pore Water	Bioassay Overlying Water
Range	9.3 – 11.5	7.3 – 7.9	7.4 – 10.2	7.6 – 9.0
Mean +/- Std dev.	10 +/- 0.61	7.5 +/- 0.19	8.4 +/- 0.85	8.2 +/- 0.35
Median	9.8	7.5	8.3	8.1

[1] All pH values in this IMDWP are in standard pH units.

Generally, bulk sediment pH measurements are higher than either pore water (collected via Trident probe) or measurements in the water overlying sediments in the bioassay tests, suggesting that bulk sediment pH provides an elevated measure of actual exposure conditions. Surface water pH greater than 9.0 coincides with bulk sediment pH values greater than 10.5. Co-located surface water samples (at a point approximately 6 inches above the sediment bed) by the Trident probe yielded no surface water pH values above 9.0 adjacent to the Site.

2.3 Shoreline Conditions

Most of the Site shoreline is sheetpile (3,442 feet) with sheer shorelines dropping to depths of 3.2 to 21 feet at the water's edge. The remainder of the shoreline is concrete bulkhead (1,503 feet) or rip-rap (824 feet) where shallow water is present at the water's edge. The concrete bulkhead portion of the Site shoreline is on a wood-pile wharf, with approximately five rows of pilings supporting the bulkhead. The rip-rap shorelines are generally steeply-sloped. Water depths along the concrete bulkhead and rip-rap areas out to 100 feet from shore range from approximately 3.2 feet to a maximum of 31.5 feet.

The Site shoreline is a restricted area and part of the Greater Detroit Foreign Trade Zone with no recreational access. Direct contact with sediment from recreational use is possible from the river, but very unlikely, and access is not available from the shore due the area's restrictive policy.

2.4 River Bottom Physical Characteristics

A multi-beam bathymetric and geophysical sensing utility mark out and obstruction survey was conducted on July 9, 2009 as part of the IMWP field activities (ARCADIS 2009b). The geophysical survey included magnetometer, side-scan sonar, and sub-bottom profiler. The primary objective of the magnetic survey was to detect the presence of ferrous debris and submerged utilities in the survey area. Objects were identified throughout the survey area and included partially exposed cables or pipelines along the southern and middle portions of the Site, and other metallic objects on the river bottom. Multi-beam bathymetry data also revealed submarine pipeline crossings and debris along the bulkhead. Side-scan survey revealed evidence of objects exposed above the sediment of the river. The sonar records show multiple pipes/cables partially exposed south of the entrance to the Wyandotte marina at the southern extent of the survey area. Shoreline rip-rap is observed in the side-scan survey approximately 50 feet into the river before transitioning to fine sediment bottom.

2.5 Sedimentation Conditions

Shoreline geometries create a velocity shadow along the southern portion of the Site, creating a depositional area along the shoreline. As a result, sediments adjacent to the Site are comprised of sediments from both upstream and local sources. The sediment thickness along the southern half of the Site ranges from 0 to 9.5 feet with an average of 4 feet. Sediment is generally thickest within approximately 100 feet from shore and becomes negligible approximately 150 to 200 feet from shore. The depth of the bioavailable zone (BAZ), as determined from SPI (see ARCADIS 2010) is between 1.1 to 4.7 inches with an average of 2.3 inches.

2.6 Habitat and Ecological Conditions

Current ecological conditions adjacent to the Site support aquatic vegetation, benthic organisms, and a resident fish community. Underwater video filmed in October 2009 showed that aquatic plants and fish were present in areas adjacent to the Site with high bulk sediment pH measurements in sediments. Fish species included goby, carp, bass, and perch. Sediment interface photos (ARCADIS 2010, Attachment 4) showed a sandy habitat layer in many areas approximately 2 inches thick, and the presence of submerged aquatic vegetation and benthic species.

The benthic community assessment conducted as outlined in the *Sediment Characterization/Remedial Evaluation Interim Measures Work Plan* (ARCADIS 2009b) found that benthic organisms were present at all locations, including upstream and adjacent to the Site; however, the communities were generally degraded at all locations.

Communities upstream and adjacent to the Site were dominated by disturbance-tolerant organisms that are generally low in abundance and diversity. Benthic organisms are generally comprised of disturbance tolerance taxa with a few sensitive taxa such as Trichoptera and Ephemeroptera. Multiple regression analysis suggests that 4,4-DDE, chloride, total PAH, dibenzofuran, bulk sediment pH, and ammonia contribute to variance noted in benthic community samples adjacent to the Site.

In addition to the benthic community analysis completed by ARCADIS, benthic community bioassays were completed by GLEC (GLEC 2009) for 12 sediment sample splits collected during the benthic community study in October 2009. Ten-day whole sediment survival and growth toxicity tests were performed with sediment samples using two benthic species (*Chironomus dilutes (tentans)* and *Hyalella azteca*) between

October 30, 2009 and November 9, 2009. Additional water quality data (temperature, pH, dissolved oxygen, and ammonia) were collected for the overlying water within the bioassay test chambers. Analysis of these results by ARCADIS indicates that multiple stressors were correlated with changes in bioassay endpoints, including a number of metals, phenol, and bulk sediment pH.

3. Interim Measures Objectives and Basis

The goal of this IMDWP is to identify an approach to mitigate potential risks associated with impaired Site sediments to a level protective of human health and the environment and to achieve sustainable risk reduction that is not reversed by recontamination from ongoing upstream sources. USEPA's Sediment Management Principle No. 1 *Control Sources Early* speaks to the importance of ongoing source considerations in reaching risk-management decisions for sediments. Source control and a risk-based decision process for sediment management are cornerstones of USEPA's *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (2005) and must be incorporated in selecting an appropriate risk management activity for sediments at North Works.

Environmental protection and sustainability considerations include reduction of sediment toxicity to benthos, reduction of exposure levels of contaminants in sediments, seasonal protection of fish during construction, maintaining stability of shorelines, and achieving equal or improved habitat quality and function adjacent to the Site.

Benefits will be sustainable if not reversed by recontamination. Potential for recontamination exists due to ongoing transport of impacted sediments from upstream areas, continuing industrial and urban sources in upstream areas, non-point urban sources to the Detroit River, and regional atmospheric sources to the Detroit River watershed.

The selected IM alternative must also minimize the potential for impact to known pipelines, utilities, or other in-water structures in the Detroit River adjacent to the Site.

3.1 Interim Measure Objectives

The specific objectives for an IM to address Site sediments are listed below:

- Remove, contain or isolate from the environment sediments that are impacted relative to upstream levels and are determined to be significant contributors ecological toxicity.
- Improve the river bottom habitat for benthos and fish.
- Maintain stability of shoreline structures.

- Minimize any deleterious short-term effects of construction.

Additionally, any appropriate IM should achieve improvements in sediment quality that are significant and sustainable based on consideration of ongoing sources and recontamination potential.

3.2 Development of Project Footprint and Remediation Limits

Development of the project footprint and remediation limits involved these steps:

- Identification of data that would be used to define the area to be remediated.
- Preparation of spatial interpretation maps of those data to identify areas to be remediated, i.e. the "footprint".
- Establishing practical remediation boundaries and areas around the footprint to identify the remediation limits.

These steps are described below.

3.2.1 Data Used for Project Footprint Development

Data used to develop the project footprint were identified based on considerations of which chemical concentrations are locally elevated relative to background levels, which chemicals are correlated with benthic community assessment and toxicity endpoints, whether depositional patterns reflect fine sediment depositional patterns, and geochemical considerations. The steps in this analysis are described in Appendix A. Bulk sediment pH levels and phenol emerge as data to be primarily used for footprint development.

The following highlights the key findings from Appendix A that inform the selection of data for project footprint development.

- Two constituents represent the key project drivers: bulk sediment pH and phenol. Bulk sediment pH values are used in the basis for the footprint development based on discussions with USEPA; however, current data are insufficient to conclude that pH exposure levels actually present in surface sediments present unacceptable risks. (This data gap is addressed later in Section 5).

- Four constituents exhibit elevated concentrations in Site sediments, weak-to-moderate association with benthic community impairment or toxicity, and a similar spatial footprint to the key drivers: total PAHs, arsenic, beryllium, and thallium.

- Metals exhibit strong correlations with one another across most Site locations and depth intervals, and spatial patterns suggest that concentrations are generally elevated in areas of greater sediment deposition (i.e., greater sediment thickness and higher percentage of fines).

- Total cyanide is elevated compared to upstream locations, however, geochemical conditions favor low bioavailability (Appendix B) and the association with Site-specific benthic community metrics and toxicity testing is weak.

3.2.2 Footprint Delineation Levels

Available information indicates that bulk sediment pH measurements are not indicative of exposure levels in pore water (see Appendix C). In addition, there is not a bulk sediment pH criterion to screen data against. A surface water criterion of pH = 9.0 does exist in Michigan; however, that criterion can be traced back to a qualitative review of the toxicity of low and high pH values to fish that was conducted by the European Inland Fish Advisory Commission (EIFAC 1969). In that review, no attempt was made to quantitatively analyze the available elevated pH toxicity tests, and invertebrates were not discussed. In addition, most of the fish studies cited by EIFAC would probably not meet current data quality requirements for inclusion in criteria derivation. Because a formal numerical derivation using the standard USEPA procedure (Stephan et al. 1985) has never been performed for pH with any data, and no invertebrate data has ever been used to determine the upper pH criterion of 9.0, this criterion must be used with caution, especially with regards to bulk sediment measurements.

To develop a bulk sediment pH value protective of surface water pH at the Site, the available paired bulk sediment and pore water pH values were used (see Section 2.2). These data show a correlation between bulk sediment Ph and surface water pH (R^2=0.6) and indicate that surface water pH > 9.0 occurs at bulk sediment value of pH = 10.5. Since surface water samples (at a point approximately 6 inches above the sediment bed) collected by the Trident probe yielded no surface water pH values above 9.0 adjacent to the Site, a bulk sediment pH value of 10.5 was used for footprint delineation. Additional data collection, as presented in Section 5, may help with establishing the relationship between bulk sediment pH and benthic community health, and/or selecting a more appropriate pH measurement endpoint and value for site management.

The central tendency (median) and upper tail of the distribution of phenol was also evaluated with a focus on the locations of distinctly higher concentrations, which occur in a limited number of cores (see Appendix A). Remediation of locations with phenol concentrations greater than 1.75 parts per million (ppm) yields a distribution of phenol for which the central tendency (median) remaining on Site is the same as upstream. Similarly, remediation of locations with phenol concentrations greater than 1.25 ppm yields distributions that have the same upper tail (high-end concentrations). Phenol concentrations of 1.25 and 1.75 ppm were used for footprint delineation.

3.2.3 Footprint Delineation

The project footprint was established through preparation of spatial interpolation maps of the surficial bulk sediment pH values, and phenol concentrations which were measured for the 0- to 6-inch layer. The 0- to 6-inch layer is conservative with respect to the 0- to 2-inch biologically active zone, and was adopted in sampling plan design at the request of USEPA for consistency with core sampling intervals (see ARCADIS 2008a for standard operating procedures [SOPs] describing core processing methods, and also ARCADIS 2009b). Actual site data from the sediment profile images indicate the oxygenated habitat layer and biologically zone to be approximately 2 inches. Iso-concentration lines at the delineation levels were established on these maps, which were then super-imposed to create a preliminary footprint that was then adjusted to include adjacent areas where core sampling showed locally elevated total PAH concentrations in surface sediments. Insufficient data are currently available to determine the type of material (i.e., constituent profile) represented by the total PAH results, or whether these higher levels are bioavailable; however, they were included in the project footprint (Figure 3-1) even though total PAHs were not identified as a driver per the decision-tree logic. As such, these potential "hot spot" areas likely associated with PAH deposition/migration from upstream areas are addressed.

3.2.4 Remediation Limits

Remediation limits were established based on the footprint by delineating practical boundaries around the footprint areas. In some cases, this includes additional areas as these more readily-constructible boundaries are established. The remediation limits for certain alternatives also considered data from deeper sediments. In particular, the core-maximum bulk sediment pH value was also interpolated (see Appendix A) and compared to assess how the footprint based on surface bulk sediment pH values would address core-maximum values for potential consideration of the extension of capping areas.

The following conditions were applied in establishing remediation limits:

- All sediments in the footprint within the Federal Channel, or within 25 feet of the Federal Channel, are removed to clean underlying material.
- For alternatives that involve cap placement, no cap placement within 25 feet of the Federal Channel.
- Due to debris limitations on the ability to achieve a defined post-removal condition, and where removal may destabilize the shorelines, no removal of sediments adjacent to the historically-filled and rip-rap armored shorelines where coarse debris is believed to underlay sediments.
- No cap placement (for alternatives that include capping) on steep slopes that may result in unstable cap conditions.
- For alternatives that involve cap placement, no cap placement at elevations where obstructions to recreational navigation would occur.

3.3 Cleanup Targets

An IM is being considered because the drivers identified are elevated in the Site sediments, are associated with impairment of benthic communities and/or benthic invertebrate toxicity, exhibit spatial patterns that may reflect local sources, and are bioavailable based on geochemical considerations.

Sediment alkalinity, as indicated by available bulk sediment pH measurements described in Section 2, is correlated with sediment bioassay and benthic community assay results, and has been a main focus of USEPA and MDNRE's concerns with respect to sediments at the Site. The cleanup target within the remediation limits is to achieve acceptable levels of water pH levels at the sediment-water interface, specifically pH values less than or equal to pH of 9. Monitoring/measurement approaches will be established in the IM design.

The overarching cleanup target is to achieve sediment quality improvements to levels at or better than upstream sediments that are sustainable in light of recontamination potential. As described in Section 2, there are multiple constituents in sediments that are elevated above BSL's, both adjacent to the Site and in upstream areas, including multiple other stressors that can adversely impact sediment toxicity. While upstream sources continue, significant improvement in benthic habitat quality is a goal. Benthic toxicity monitoring approaches will be established in the IM design.

4. Evaluation of Interim Measure Alternatives

4.1 Evaluation Criteria

This section presents the criteria used to evaluate the IM alternatives presented in Section 4.3, and an individual evaluation of each alternative with respect to these criteria is provided in Section 4.4.

The nine criteria summarized in the *RCRA Corrective Action Plan (CAP) Guidance* (USEPA 1994b) used for evaluating the selection of a final IM alternative include:

- Protect Human Health and the Environment
- Attainment of Cleanup Goals
- Control the Sources of Releases
- Compliance with Applicable Waste Management Standards
- Other Factors:
  - Long Term Reliability and Effectiveness
  - Reduction in the Toxicity, Mobility or Volume of Wastes
  - Short-term Effectiveness
  - Implementability
  - Cost

The selected IM alternative must comply with the first four RCRA screening standards. The fifth standard "Other Factors" (including Long Term Reliability, Reduction in Toxicity, Mobility or Volume of Wastes, Short-term Effectiveness, Implementability and Cost) includes general decision factors that are considered appropriate in selecting a remedy that meets the four required criteria (USEPA 1994b).

4.1.1 Protect Human Health and the Environment

This criterion is used to evaluate whether an alternative adequately provides protection of human health and the environment; how site risks associated with impacted sediments are eliminated, reduced, or controlled through natural processes, treatment, engineering, or institutional controls; and the extent to which each IM alternative meets the goals established in Section 3. This evaluation encompasses an assessment based on a composite of factors addressed under other evaluation criteria, including long-term effectiveness and monitoring, short-term impacts and analysis, and compliance with applicable standards, guidance and criteria.

While no site-specific risk assessment has been conducted to determine if potential risks are associated with exposure to sediments adjacent to the Site (and data are currently inadequate with respect to pH exposure and contribution to toxicity), the ability of a particular alternative to achieve and maintain the relevant sediment and surface water screening levels will be considered under this criterion.

The IM alternative must satisfy this criterion. The IM alternative may include those measures that are needed to be protective, but are not directly related to media cleanup, source control, or management of wastes.

4.1.2 Attainment of Cleanup Goals

This criterion is used to evaluate whether an alternative addresses and is capable of complying with the cleanup goals and objectives as discussed in Section 3.2.

4.1.3 Control the Sources of Releases

This criterion is used to evaluate whether an IM alternative is capable of controlling or eliminating further releases of a constituent that may pose a threat to human health or the environment. None of the site-specific alternatives address ongoing upstream sources from the industrialized urban watershed. An effective upstream source control program is essential for the long-term effectiveness and protectiveness of the IM (especially for sediments cleanups and Source Control is USEPA Sediment Management Principle #1 [USEPA 2005]); however, it may not be technically feasible in all scenarios. In the case of the Trenton Channel, as described in Section 2, multiple continuing sources of many contaminants occur. However, sources of alkaline material to the river, the cause of high pH levels in sediment, have been abated decades ago by changes in manufacturing and waste disposal practices – although illicit dumping and disposal can occur along the Detroit River for various types of waste materials.

4.1.4 Compliance with Applicable Waste Management Standards

This criterion assesses whether the specific waste management activities that will be conducted for the IM alternative comply with all applicable state or federal regulations.

4.1.5 Long Term Reliability and Effectiveness

Long-term effectiveness and monitoring refers to the period after the IM alternative has been completed and short-term effectiveness limitations have been resolved. This criterion assesses the magnitude of human health and ecological risk remaining at the Site subsequent to implementation and completion of the IM; the adequacy and reliability of controls that could be implemented to monitor and manage the residual risk; and the potential need to replace technical components of the IM alternative, such as a cap or a treatment system, and the potential risk posed by that replacement.

4.1.6 Reduction in the Toxicity, Mobility, or Volume of Wastes

This criterion is used to evaluate the anticipated performance and efficiency of the IM alternatives at reducing the toxicity, mobility, or volume of site constituents. The assessment focuses on the magnitude, significance, and irreversibility of the treatment.

4.1.7 Short-term Effectiveness

This criterion is used to evaluate the effectiveness of an IM alternative in the short-term on ecological and human risks, including environmental impacts of implementation, potential impacts to the community and Site workers during IM implementation, and time until the IM is achieved. This evaluation determines whether the IM alternative has significant short-term effectiveness, or potential adverse impacts, and whether any impacts identified can be eliminated or controlled through proper IM selection and best management practices (BMPs) to be followed during IM implementation.

4.1.8 Implementability

This criterion assesses the technical feasibility, administrative feasibility, and availability of necessary materials, resources or other needs for implementing an IM alternative and is often a determining variable in IM selection. Technical feasibility refers to construction and process operations, reliability, and ability to comply with regulatory and monitoring requirements, and ease of undertaking additional action if the IM fails. Administrative feasibility refers to gaining regulatory or other agency approval and coordinating with other offices and agencies for activities such as obtaining permits for offsite actions, access to rights of way, and implementing institutional controls. Lastly, the evaluation considers the availability of services and materials necessary to support each IM alternative, such as treatment, storage, and disposal facilities.

4.1.9 Cost

This criterion is used to evaluate the estimated total cost to implement the IM alternative. The total cost of each IM alternative represents the sum of the direct capital costs (materials, equipment, site development, and labor), indirect capital costs (project/construction management, engineering and administration, and contingency allowances), and operation and maintenance (O&M) costs. Costs are developed using current and generally accepted engineering cost estimation methods and are based on a review of literature, vendor quotations, professional judgment, and experience from similar projects.

4.2 Technology Identification and Screening

This section identifies technologies and General Response Options (GROs) that are potentially appropriate for addressing Site sediments. A brief description of each technology is provided below, based on the technology's applicability to the project objectives, and determines whether or not the GRO was retained beyond this initial technology screening process. If a technology is retained beyond this screening, it will be used to assemble the IM alternatives.

4.2.1 No Action

Under "No Action", no remedial action is implemented. Remedial action can include containment, removal or treatment of contaminated sediments, engineering controls, or institutional controls. The No Action alternative is generally appropriate in situations where contamination at a site presents no current or potential threat to human health or the environment, when RCRA does not provide the authority to take remedial action, or when a previous response action has eliminated the need for additional remedial action at a site. The No Action response option would not change the existing sediment conditions, except by those processes that are known to be occurring naturally.

No Action Assessment

As is typical in feasibility studies, the No Action GRO will be retained for further evaluation to serve as a baseline for comparison with other response options retained beyond the technology screening and between IM alternatives.

4.2.2 Institutional Controls

Institutional controls are defined as non-engineering, administrative, and/or legal controls at a site intended to prevent or reduce human exposure to hazardous substances. Site use and access restrictions may be applied to control use or disturbance of resources potentially exposed to or affected by impacted sediments (e.g., surface water and fish) that would otherwise pose danger to human health or the environment if not addressed by remediation.

Institutional Controls Assessment

Institutional controls implemented at the Site are likely to include perpetual restrictions or limitations on shoreline access and Site development activities. These controls are anticipated to limit human exposure to direct contact with potentially impacted Site sediments. However, the intent of this document is to implement an IM at the Site to address specific impacted sediment adjacent to the Site and resulting reduced water quality. Thus, institutional controls were not retained for further evaluation as an IM alternative.

4.2.3 Monitored Natural Recovery

Monitored natural recovery (MNR) refers to the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup approach, to achieve site-specific remediation objectives (e.g., reduction of volume and toxicity of contaminants) within a timeframe that is reasonable as compared to that offered by other more active methods. Impacted sediments are left in place and existing processes (physical, chemical, and/or biological) are relied upon to contain, destroy, alter, or otherwise reduce the bioavailability and toxicity of contaminants (Magar et al. 2009; NRC 1997).

Extensive site monitoring and modeling are performed as part of MNR to demonstrate that contaminant reduction is occurring, and that the reduction is achieving cleanup goals. Long-term monitoring is sometimes conducted for multiple media including the sediments, water column, and biota – although benthic toxicity monitoring is a likely monitoring endpoint of interest for the Site. Reduction in toxicity can be documented by trends or by documenting changes in concentrations of constituents contributing to toxicity. Monitoring to evaluate progress of the natural attenuation processes is an integral component of the MNR remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (US Department of Energy [USDOE] 1997).

Natural processes that can contribute to MNR are briefly summarized below.

Physical Processes

Physical processes promote natural attenuation in sediments through several mechanisms. Advection, dispersion, and burial are purely physical processes that reduce risk by lessening the concentration of constituents of concern (COCs) at points of exposure, such as in the biologically active surficial sediment layer. Advection refers to the movement of dissolved COCs in flowing water, while dispersion describes the spreading of the dissolved contaminants along the direction of the flow as well as away from the flow. Burial by natural deposition of cleaner sediments is another purely physical process that occurs in areas of sedimentation. When COC sources have been contained, removed, or otherwise controlled, cleaner sediments depositing on impacted sediments mix with and effectively reduce constituent concentrations at the point of exposure, which is at or near the sediment surface for most receptors.

Physical-chemical Weathering and Geochemical Transformation

Physical-chemical weathering alters compositions and concentrations of COCs in surficial sediment through dissolution, evaporation, sorption, and photo-oxidation. In dissolution, the different constituents dissolve into interstitial and overlying water as a function of their solubility, depleting the concentrations of the more soluble COCs. Evaporation, or volatilization, is not a significant process in subsurface sediments, or surficial sediments that remain submerged. Sorption refers to the physical and chemical binding of constituents to sediment particles. As COCs weather, the more persistent components can become sequestered in the sediment material phase

(Pastorok et al. 2000; Neff et al. 2001) through chemical sorption. Physical-chemical weathering processes reduce risk through depletion of the more bioavailable COCs and sequestering of the less bioavailable COCs through sorption, reducing their bioavailability even further. Under reducing conditions such as those found in organic sediments, iron (and manganese) oxides found in the mineral fraction of the sediment are reduced to metastable sulfides known as acid-volatile sulfides. The solid phase sulfides bind cationic metals, rendering them unavailable and non-toxic to biota (Rand 1995).

Additionally, the sediment is subject to geochemical processes that have and continue to affect the alkalinity of the surrounding water. Calcium hydroxide (present in the distiller blow-off sediment that has been in contact with the Detroit River over a period of decades) is reasonably soluble in water, and in the absence of passivation or other geochemical reactions or processes would have likely dissolved into the water. XRD analysis of sediment cores have identified calcium hydroxide, indicating that there are geochemical processes that may have preserved the sediment in its current form over a period of decades arguing for a notably effective preservation process. Appendix C describes the carbonation process that is assumed to be occurring to the calcium hydroxide. The outcomes of this chemical reaction are conducive to both the preservation of the calcium hydroxide-bearing sediment in a freshwater environment as well as the "passivation" of residual calcium hydroxide that are rendered unable to impart further alkalinity to any contacting water. The XRD-based identification of the minerals ettringite and thaumasite, both relatively soluble phases, supports the concept that the alkaline sediment has not undergone intensive leaching of alkalinity; otherwise these minerals would be absent. This preservation is consistent with consumption of porosity due to the carbonation of calcium hydroxide and the formation of phases like ettringite and thaumasite. Appendix C more fully discusses the significance of these phases and the geochemical reactions contributing to their formation and the preservation of the alkalinity within the sediments.

Biological Degradation

Biological degradation processes complement physical-chemical processes. Although rates of biodegradation are typically driven by nutrient availability, the mechanism of degradation is determined by the oxidation-reduction conditions of the sediment and the nature of the microbiological community (Atlas et al. 1981). Diagenesis of organic material contributes to alkalinity reduction within Site sediments. The existing organic matter buried by the sediments reacts with available electron acceptors (i.e., oxygen, nitrate and sulfate) within the overlying water body to produce reaction products that include electron donors such as ammonium, methane, and hydrogen sulfide, as well as carbon dioxide and water (Stumm and Morgan 1981). The addition of carbon dioxide to the overlying water body decreases pH.

MNR Assessment

Some or all of the natural processes identified above may be occurring at any given time or location in sediments at the Site. The net result of such processes is attenuation of contamination levels in surface sediments – except as limited by ongoing sources or remixing with or re-exposure of deep sediment. There is evidence of MNR processes, specifically geochemical transformations that contribute to reduction in surface sediment exposure levels, for example bulk sediment pH levels at the southern portion of the Site. Additional data and investigations would be required to provide a better understanding of currently ongoing MNR processes.

MNR can be implemented alone, along with an active remedial action, or after an active remediation is completed. Natural attenuation that depends primarily on sediment burial may not be appropriate in defined navigation channels where dredging is required to maintain navigational draft.

MNR is readily implementable and has the advantage of avoiding inevitable consequences of more invasive GROs (such as cap placement and sediment removal). MNR has been retained for further analysis and IM alternative assembly for all or part of the Site.

As is discussed in Appendix C, the alkaline-impacted sediment must have already been "passivated", thereby significantly limiting the release of alkalinity. The fact that there is a persistence of any internal alkalinity within the alkaline-impacted sediments argues that limited release of alkalinity is possible given that reasonably soluble components such as calcium hydroxide are still present in sediments that have been exposed to a freshwater environment for decades. Appendix C also discusses the various geochemical processes that, working singularly or in concert, result in a degree of preservation and passivation and resulting minimal current or future release of alkalinity in the current undisturbed setting. Thus, based on the current geochemical understanding of the system, and anticipated continued accumulation of non-alkaline overlying sediments along shore in this area, it is likely that MNR would continue to be effective in limiting the alkaline impacts of the sediments. Active remedies, while potentially increasing the rate at which recovery may occur, may also result in the uncontrolled release of residual alkalinity that is currently sequestered within the passivated sediment if disturbed, and destabilize or even reverse the recovery that has already occurred.

4.2.4 Cap/Backfill Technologies

4.2.4.1 Cap Technology

Cap technology is an accepted and approved approach for managing potential risks posed by sediments (USEPA 1996). In-situ subaqueous capping involves the placement of a clean cap over an area of impacted sediment to sequester those sediments from the BAZ within the sediment bed and isolate those sediments from resuspending into the overlying water column. Under the proper circumstances, it is a viable approach for remediating impacted sediments. Caps may be constructed of clean sediment, sand, gravel, and/or amended material, or may, if necessary, involve a more complex design using geotextiles, liners, reactive materials, or sorbent materials.

In-situ capping has been applied in a variety of settings very similar to North Works including rivers, near-shore areas, and estuaries. Conventional marine construction equipment and techniques can be used for capping projects, or conventional equipment may be modified for specific applications (as in the case of low-impact placement to avoid sediment compaction or resuspension).

While caps have been effectively used as a stand-alone remedy, providing both physical and chemical isolation of the impacted sediments, in recent years they have also been incorporated into multi-component approaches (i.e., hybrid remedies) - used in areas of less toxicity that do not warrant the extent of remediation provided by dredging. Such instances are site-specific but may include division of the site into smaller areas, or specific management units.

Various documents are available that provide technical guidance for utilizing in-situ subaqueous capping as a remediation technique for impacted sediments (such as USEPA guidance [Palermo et al. 1998]), and include detailed guidance on site and sediment characterization, cap design, equipment and placement techniques, and monitoring and management considerations. As capping is a technology that is proven, but also continues to develop, new findings or approaches based on continuing research and case histories would also be considered, as appropriate.

There are various design bases for the consideration and implementation of an in-situ subaqueous cap. The most common include the following factors:

- Physical isolation of the affected sediment from the benthic environment and potential human exposure.
- Physical isolation of the affected sediment, preventing resuspension and transport to other sites.
- Reduction of the flux of dissolved constituents into the water column (Palermo et al. 1998).

The physical barrier provided by cap placement immediately sequesters the non-native sediment layer, preventing contact with the overlying water column and reducing or eliminating benthic and/or human exposure. The physical barrier also reduces the potential mobilization of these sediments. A properly designed cap can provide a stable and long-lasting physical barrier that will satisfy the project goal of isolation of non-native sediments and achievement of the remedial objectives. In addition to the immediate utility of the cap as a physical barrier, the cap can also provide a chemical barrier to the advective or diffusive transport of dissolved compounds from the sediment bed to the overlying water column.

To achieve these results, an in-situ capping project must be treated as an engineered project with carefully considered design, construction, and monitoring. The basic criterion for a successful capping project is simply that the cap required to perform some or all of these functions be successfully designed, placed, and maintained (Palermo et. al 1998).

4.2.4.2 Backfill Technology

Backfill technology are applications typically utilized in environmental settings which exhibit minimal levels of contamination and toxicity to ecological and human receptors. Backfill layers can be implemented as a stand-along remedy or in combination with other remedial actions as contingency measures. Backfill applications are a widely accepted contingency measure utilized to address residual contamination following dredging activities. Various documents are available that provide technical guidance for utilizing backfill layers as a remediation techniques for impacted sediments (USEPA 2005; Palermo et al. 2008).

Backfill applications typically consist of a thin layer of clean material (usually a few inches) placed over low toxicity sediment or residuals to provide short-term isolation and long-term reduction in surficial contamination. The clean material utilized in the cover material does not necessarily need to be sand; in fact, other materials with the potential to reduce the bioavailability of the contaminants (such as clay and organics) may be preferable (Palermo et al. 2008). Similar to cap constructions described above, conventional marine construction equipment and techniques can be used for backfill applications, or conventional equipment may be modified for specific functions (as in the case of low-impact placement to avoid sediment compaction or resuspension).

When placed, backfill applications can prevent impacted sediment contact with the overlying water column thereby reducing or eliminating benthic and/or human exposure. In addition, the potential mobilization of these sediments is reduced. Furthermore, the mixing of backfill materials and low level contamination or residuals results in an immediate reduction in contaminant concentrations in the BAZ. At some sites, covers may also provide physical and chemical isolation of the residuals, depending on the thickness of the cover, the thickness of the residuals layer, and the rate of sediment mixing. The additional deposition of clean sediment in the short or long term may extend and enhance the isolation ability of a cover.

4.2.4.3 Types of Cap/Backfill Technologies

The primary types of cap and backfill technologies used in environmental remediation and considered during this evaluation include thin layer backfill, isolation caps, and active caps. Each of these technologies are briefly described below.

Thin Layer Backfill

Thin Layer Backfill also known as residuals caps, sand covers, and residual cover layers (hereafter referred to) is the placement of a thin layer of clean material over impacted sediment with the intent to provide a reduction of sediment concentrations exposed within the BAZ (at the sediment surface) and to accelerate natural recovery within the underlying sediments. Studies have indicated that even very thin layers of clean material placed on the sediment bed can result in a dramatic reduction in the interaction of sediment-associated contaminants with the overlying water column. The engineered application of a residual cover layer can be considered an alternative to placement of a cap. A residual cover layer differs from an isolation cap as it is designed to provide short-term isolation and reduction of remaining contamination as opposed to long-term containment. While the thickness of an isolation cap can range up to several feet, a residual cover layer can consist of as little as a few inches of clean material. Placement of a lesser volume of materials typically creates fewer short-term environmental impacts allowing the benthic population, which is inevitably disturbed during materials placement, to reestablish more rapidly; allows for minimal impact to navigation traffic; induces minimal sediment consolidation; and requires no monitoring or maintenance activities. Residual cover layers can be used to enhance natural recovery because the addition of clean material can provide dilution of the surface sediment constituents and accelerate the rate of natural recovery. The thickness of the residual cover layer is determined by the degree of residual contamination and the enhanced natural recovery desired, as well as the anticipated impacts of material mixing with the underlying sediments as a result of both placement and bioturbation. Material mixing will provide some stability to the cover layer; however, residual cover layers are susceptible to resuspension and downstream transport as cover thicknesses are not protective of erosive forces.

Isolation Cap

An isolation cap consists of sand, soil, or a mixture thereof, which is placed on the sediment surface, typically without any prior removal of sediments, to provide for immediate, long-term isolation of the underlying constituents. However, removal can be conducted in the instance of a hybrid remedy prior to cap placement if a specific water depth is maintained to support navigation, preserve aquatic habitat, or address floodplain compensation concerns. The required thickness is typically determined by one-dimensional mass transport analytical models (USEPA 1996; Palermo et al. 1998). This model and the selection of cap material(s) depend on site-specific characteristics identified within the conceptual site model. Bioturbation depth, constituent migration through the cap, consolidation of underlying sediments, effect of total placement volume on project duration, impacts to commercial/industrial navigation, and the precision of, and mixing induced by, the placement methods must also be considered when evaluating the applicability and in determining the targeted thickness. The cap material(s) will be selected to provide stability and chemical transport retardation with the potential for natural chemical degradation (attenuation) beneath the cap. Depending on the specific conditions at the site, the isolation cap may consist of other layers in addition to that specifically designed for chemical isolation. Additional layers (such as geotextile) may be incorporated to improve physical stability between the cap and the existing sediment. In higher energy environments, an armor layer may be provided to protect the isolation layer from erosive forces. Habitat reconstruction opportunities may also be viable for implementation as a component of an isolation cap. Placement of the cap will inevitably result in the burial of macro invertebrates; however, placement of a clean material layer alone (i.e., sand) may promote ecological repopulation without additional habitat restoration activities. There are situations when conventional isolation caps might not be sufficiently protective. For example, highly contaminated sediments over time may mix into and then be released from the cap into the overlying water column. Implementation of an isolation cap requires long-term monitoring of cap integrity and it's achievement of project objectives. The degree of maintenance required is dependent on observations and results of the monitoring events.

Active Cap

Cap design has recently become more focused on the potential for increasing the effectiveness of the cap by addition or amendments of other material(s) to create an "active cap". These active caps incorporate specific materials or layers to encourage fate processes, such as increasing degradation of contaminants sequestered within the cap. As stated above, caps that encourage degradation or sequestration of the contaminants may be more effective at sites that contain highly contaminated sediments as they provide immediate, long-term contaminant containment and reduction as opposed to solely providing sediment isolation (short- or long-term). Potential cap amendments to encourage the fate processes may include:

- AquaBlok™ – utilization of bentonite clay to provide a low-permeability layer designed to decrease bed permeability and control advective transport rates.

- Coke breeze, activated carbon, or organoclay sorbents - to increase sorption and sequestration, resulting in greater retardation of mass transport through the cap.

- Apatite (or other phosphate minerals) - to increase sorption and reaction of metals within the cap.

- Zero-valent iron - to increase dechlorination of organics and metals reduction.

- Pyrite – utilization of iron sulfide to encourage alkalinity reduction.

- Siderite – utilization of iron carbonate to reduce alkalinity.

Cap amendment selection is specific to site characteristics; however, if an accurate selection is made, an active cap is effective at mitigating sediment impacts via separation of reactive sediments from contact with surface water and/or potential receptors and installation of a low-permeability cap to prevent pore water migration into the water column. Active caps have become readily accepted as effective remediation designs for contaminated sediment sites and have been successfully implemented on numerous documented occasions. However, some materials used as the active component of the cap may require bench-scale testing and/or further development for application in this setting, such as pyrite and siderite (which has a strong buffering capacity and slower kinetics of dissolution). A geochemical evaluation for use of these materials as viable amendments within an active cap has been provided in Appendix C.

Similar to isolation cap installation, the targeted thickness for an active cap will be dependent on bioturbation depth; constituent migration through the cap; consolidation of underlying sediments; effect of total placement volume and accuracy required during placement on project duration; impacts to commercial/industrial navigation; and the precision of, and mixing induced by, the placement methods. In addition, as installation of the cap will inevitably result in the burial of macro invertebrates, placement of clean materials may promote ecological repopulation without additional habitat restoration activities. Implementation of an active cap requires long-term monitoring of cap integrity and it's achievement of project objectives. The degree of maintenance required is dependent on observations and results of the monitoring events; however, continual maintenance and material replacement may be required if the active cap material components are to become exhausted.

Implementation of an active cap was not retained based on the lack of documentation available for the reaction of Site constituents with commercially available, documented and widely accepted reactive cap materials. Possible "active cap" material(s) that could be utilized to counteract the current constituent concentrations would result in the formation of precipitates beneath the cap and along the channel bottom. Some of the materials determined effective at reducing the alkalinity without producing precipitates would require continued cap maintenance and replacement based on the fast reaction kinetics and rapid material exhaustion. Continued research is being conducted on reagents that may be appropriate and viable for alkalinity reduction without precipitate formation or rapid kinetics; such materials include pyrite and siderite. The use of such materials has not been proven in the field as viable options.

Habitat reconstruction opportunities may be viable components of capping/backfill remedial options. The material utilized for a backfill residuals cover layer and/or an engineered isolation cap may serve as the substrate for habitat reconstruction. Materials such as sand or similar granular material may provide suitable habitat for biota whereas armoring materials may provide for fish spawning and benthic macroinvertebrate recolonization. Furthermore, materials such as large woody debris, boulders and/or subaquatic vegetation can be added to the surface of the cap material to provide structure and habitat in unconsolidated bottom environment. Furthermore, the reconstruction of habitat could rely on natural riverine processes (i.e., deposition) to aid in the replacement and enhancement of the system following cap/backfill construction. Habitat delineation and assessment activities would be conducted during pre-design activities and if determined suitable, implementation of habitat reconstruction opportunities would be evaluated during the design phase.

Cap/Backfill Technologies Assessment

The three cap/backfill technologies discussed above were evaluated for application and implementation as an IM alternative at the Site. Several important distinctions among the capping methods warrant consideration for applicability at the Site and thus are presented in Table 4-1 for ease of review and comparison, as well as discussed below.

Table 4-1 – Backfill /Cap General Remedial Options

Screening Criteria	Backfill/Capping General Remediation Options		
	Residual Cover Layer	**Engineered Isolation Cap**	**Active Cap**
Isolate Sediment from Benthic Community	Provides immediate reduction of surface concentrations, but long-term stability of a thin layer relies on hydrodynamic forces.	Thickness and layers selected based on Site-specific conditions for immediate and long-term isolation of benthic community.	Thickness and layers selected based on Site-specific conditions for immediate and long-term isolation of benthic community.
Isolate Sediment from Resuspension/ Transport	May provide some stability after mixing; however, cover may not be protective against excessively strong erosive forces.	Isolates and protects sediment sequestered under cap, an armor layer may be utilized to protect from erosive forces.	Isolates and protects sediment sequestered under cap, an armor layer may be utilized to protect from erosive forces.

Screening Criteria	Backfill/Capping General Remediation Options		
	Residual Cover Layer	**Engineered Isolation Cap**	**Active Cap**
Reduce Flux from Sediment to Water	Decrease in surface concentration from material placement/dilution. Chemical migration through the cover is dependent upon cap thickness and natural organic content of the backfill material(s).	Provides long-term isolation and containment of sediment constituents. Chemical migration through the cap is dependent upon cap thickness and natural organic content of the cap material(s).	Provides long-term isolation and containment to sediment constituents. Chemical migration through the cap is dependent upon cap thickness and chemical characteristics of the cap material(s). Reduces constituent mass/concentration by increasing sorptive capacity or by encouraging chemical reactions.
Ease of Construction/Availability of Materials	Relatively easy to implement. Materials and equipment are readily available.	Relatively easy to implement. Materials and equipment are readily available. Filter component (i.e., geotextile) placement may increase complexity of cap construction.	Slower construction may be necessary to reduce placement variability of layers containing reactive materials. Reactive materials could be costly. Filter component (i.e., geotextile) placement may increase complexity of cap construction. Most materials and equipment are readily available.
Effect on Biota	Placement of a lesser volume of material typically creates fewer short-term environmental impacts, allowing the benthic population to reestablish faster.	All placement and thickness options would result in burial of macro invertebrates; however, placement of clean material may promote repopulation by more desirable species. Habitat reconstruction opportunities may be viable in coordination with this technology.	All placement and thickness options would result in burial of macro invertebrates; however, placement of clean material may promote repopulation by more desirable species. Habitat reconstruction opportunities may be viable in

Screening Criteria	Backfill/Capping General Remediation Options		
	Residual Cover Layer	**Engineered Isolation Cap**	**Active Cap**
			coordination with this technology.
Effect on USACE Navigation in Use Area	Little to no impact on navigation.	Placement of cap decreases water depth; effect on navigation will be dependent on elevation of final cap surface	Placement of cap decreases water depth; effect on navigation will be dependent on elevation of final cap surface
Placement Techniques	Mechanical or hydraulic placement techniques are viable. Selection would be dependent upon site characteristics (i.e., hydraulics, water depth, etc) and backfill material properties.	Mechanical, hydraulic, or pneumatic placement techniques are viable. Selection would be dependent upon site characteristics (i.e., hydraulics, water depth, etc) and cap material properties. Mechanical equipment is required for placement of certain cap components (i.e., geotextiles).	Mechanical, hydraulic, or pneumatic placement techniques are viable. Selection would be dependent upon site characteristics (i.e., hydraulics, water depth, etc) and cap material properties. Mechanical equipment is required for placement of certain cap components (i.e., geotextiles and active mats).
Sediment Bed Consolidation	Will induce minimal sediment consolidation.	Sediment consolidation will be dependent upon cap materials and thickness and sediment characteristics.	Sediment consolidation will be dependent upon cap materials and thickness and sediment characteristics.

Screening Criteria	Backfill/Capping General Remediation Options		
	Residual Cover Layer	**Engineered Isolation Cap**	**Active Cap**
Effect on Project Duration	Based on volume of backfill materials, placement should not significantly impact project duration.	May lengthen project duration if significant volume is required for cap placement. Duration would also increase if multiple lifts are required. Addition of filter component may increase duration due to complexity of installation.	Project duration variable dependent on number of layers within cap and volume of material(s). Addition of filter component may increase duration due to complexity of installation. Accuracy of placement to reduce variability could also increase duration.
Maintenance	Requires no maintenance.	Requires long-term monitoring of cap integrity. Degree of maintenance is dependent on observations and results of monitoring events.	Requires long-term monitoring of cap integrity. Degree of maintenance is dependent on observations and results of monitoring events. Continual maintenance and material replacement could be required if reactions cause exhaustion of the active cap material component.

Site conditions, more than any other factor, will dictate the feasibility of in-situ cap/backfill technologies. Site characteristics affect all aspects of a cap/backfill application, specifically capping, including design, material(s) selection, construction equipment selection, implementation, monitoring, and maintenance programs. Site conditions that must be considered include the physical channel environment, existing habitat, hydrodynamic conditions, sediment characteristics, available land for staging materials and equipment, and existing or future potential uses of the waterway.

The following characteristics require consideration during the evaluation and selection of a capping approach:

- Channel flow velocities
- Wind waves and vessel wakes
- Water depths for navigation
- Side slopes
- Bank stability
- Presence and types of debris

Potential limitations on cap implementation include:

- Maintenance dredging areas for navigation
- Permitting requirements

Capping construction, if retained as a viable IM alternative, would not be implemented within the designated Trenton Federal Navigation Channel due to periodic maintenance dredging required to support large commercial vessel drafts.

Capping would provide isolation and sequestration of materials within the footprint where it can be implemented subject to the considerations above. Capping technologies have been retained as viable component of IM alternatives.

4.2.5 Removal and Ancillary Processes

This section discusses the technologies available for the removal of contaminated sediments from the channel bottom and the ancillary processes that must be conducted subsequent to removal, such as transportation of excavated materials, sediment processing (i.e., dewatering and treatment), and disposal.

4.2.5.1 Removal

Removal refers to excavation, or dredging, employed to permanently remove impacted sediments for ex-situ treatment, confinement, or disposal. Dredging is a well-developed technology and has evolved as a primary remedial option recommended by USEPA for contaminated sediment sites (Palermo et al. 2008). The primary function of dredging is to physically remove sediment from its in-situ aquatic environment. By removing contaminants from an impacted environment, dredging has the potential to greatly reduce mobility and exposure of contaminants to humans and ecological receptors.

As specified in the Technical Guidance for Environmental Dredging of Contaminated Sediments (Palermo et al. 2008), the design bases for an environmental dredging operation commonly includes:

- Dredge with sufficient accuracy such that contaminated sediment is removed and sediment cleanup levels are met without excessive removal of clean sediment.
- Dredge sediments in a reasonable timeframe and in a condition compatible with subsequent transport for treatment or disposal.
- Reduce and/or control resuspension of contaminated sediments, downstream transport of resuspended sediments, and releases of COCs to water and air.
- Dredge sediments such that generation of residuals is reduced and/or controlled.

Dredging, or hereafter referred to as removal, is a common practice for managing impacted sediments but use of the technology and selection of the appropriate equipment requires careful consideration as it has a high degree of uncertainty and variability surrounding its implementation. Key inputs to dredging include the location, type and volume of sediment to be removed, as well as many key site characteristics including site and water access; water depth, channel hydraulics, and river bed characteristics; proximity to shoreline and the navigation channel; and the potential presence of debris, shoreline structures, in-water structures, bedrock or hardpan, and vegetation (both subaquatic and shoreline). Other considerations such as sediment transportation, processing and disposal options are key elements in the selection of an appropriate dredging methodology and are discussed in further detail below (Section 4.2.5.2).

Although numerous removal approaches and equipment types are commercially available to address site-specific conditions and constraints, two basic categories comprise removal technology; mechanical and hydraulic.

Mechanical

Mechanical dredging removes bottom sediment through the direct application of mechanical force to dislodge and excavate the material. The dredged material is then lifted mechanically to the surface at nearly in-situ densities (Averett et al. 1990). Mechanical dredging utilizes an excavation bucket via suspended or articulated fixed arm support typically operated by a crane or excavator situated on land or fixed on a flat deck barge. Common mechanical dredge types include dragline, clamshell, dipper, and bucket ladder.

Dredged materials are typically deposited in a barge and transported to a land-based staging area for processing and disposal. If dredging equipment can be positioned on the shore, dredged materials would preferably be directly deposited in the staging/processing area to avoid additional handling of the material. Low water content is a desired result of dredging activities to minimize and/or avoid additional processing following removal, which will ultimately reduce project duration and cost.

Removal via mechanical technologies is not efficient in dredge areas located adjacent to bedrock, or large, irregular debris fields, may require additional passes to meet the specified sediment removal quantities, and may result in resuspension of contaminated sediments. Resuspension of sediments can be limited by the implementation of engineering and operational controls (i.e., silt curtains and reduced production rates).

Hydraulic

Hydraulic dredges remove and transport sediment in a slurry form. The dredges typically have a suction device fixed to a moveable arm (or ladder) that is raised or lowered to facilitate sediment removal. The suction end of the dredge is often equipped with a mechanical or hydraulic device to loosen the sediment prior to being drawn into the dredge suction line. Common hydraulic dredges include plain suction, the conventional round cutterhead, horizontal auger cutterhead, open suction, dust pan, and diver-assisted suction dredges.

Important considerations when evaluating hydraulic dredging as a method for sediment removal include:

- The presence of debris within the removal area will greatly reduce the effectiveness of a hydraulic dredge (Averett et al. 1990).

- The quantity of water requiring treatment after dewatering from the dredge slurry could be significant, as this technology tends to entrain substantial quantities of water. Factors influencing the solids content include dredge type, nature of sediment, condition of equipment, and operator skill and experience.

- Pipelines and in-water equipment may interfere with channel navigation and boat traffic patterns.

- Additional ladder pumps are required when depths to targeted materials exceed 25 to 30 feet or booster pumps when transporting material significant distances via pipeline.

4.2.5.2 Transportation, Sediment Processing and Final Disposal

Apart from actual dredging, a significant component of sediment removal involves transport, processing or treatment (dewatering of the dredged material) and final disposal. Transport and disposal of the dredged material account for a major portion of the total cost of remediation projects, and the ability to process the sediment may be the rate-limiting step when planning the overall schedule (Palermo et al. 2008).

Transportation

Transport of excavated sediments links all dredging components and may involve several different technologies or modes of land- water-based transport, such as barges, trucks, railroads, or pipelines (Palermo et al. 2008).

Transportation of sediments via land can either be by truck or rail. Considerations of land transport include increased traffic and risk associated with transport of sediments through the local communities; the ability to obtain reliable services and equipment consistent with project schedule and objectives; and the existence of the necessary infrastructure for offloading.

In-water transportation considerations mainly include sediment transport via barge or pipeline. Barge transport is usually used for bulk sediments removed by mechanical dredging whereas pipeline transport is usually implemented in association with hydraulic dredging. The primary in-river transportation issues include increased vessel traffic due to construction vessels, coordination with commercial/recreational vessels, compliance and coordination with local navigation authorities, pipeline disturbances, and appropriate water depths.

Land-transport was not retained based on the location of the facility selected for final disposal, as discussed below. Transportation of sediments via pipeline was not retained based on requirements identified for implementation (i.e., obtaining access agreements) of a pipeline to extend both on-land and in-water with numerous pumping stations to maintain terminal velocity and prevent material fallout, requirement for continual monitoring and maintenance activities, and need to coordinate/implement navigational traffic controls. Thus, barge transport will be retained for the remaining evaluations and during assembly of IM alternatives. Known limitations that exist for barge transport include vessel availability, existing water depths, coordination of in-water traffic, obstructions in route to disposal, and barge access/off-loading at the disposal facility. Currently, none of these limitations are anticipated to be an issue at the Site.

Sediment Processing

In addition to transportation logistics, there are multiple processing options for excavated sediments which may be utilized to achieve project objectives (i.e., dewatering, stabilization, treatment). The option selected is primarily dependent on the volume and water content of removed material. Unless the material can be barged or hydraulically conveyed to the disposal facility (e.g., confined disposal facility [CDF]), dredged sediment may contain large percentages of water to be safely transported offsite or placed within a disposal facility. Dewatering options for dredged sediments generally range from passive (e.g., gravity dewatering) to mechanical dewatering methods (e.g., solidification); additives may be used to enhance dewatering, but may increase the net sediment volume for disposal. Dewatering is generally time consuming, costly, and requires large operating areas; yet necessary for compliance with most transportation and disposal requirements. The magnitude and extent of water management depends on the dredging and dewatering methods utilized. In some cases, free water can be returned to the dredge site, which usually requires treatment prior to discharge, or water can be sent offsite for treatment.

Dewatering of sediments is not currently anticipated based on the disposal option, further described below. Therefore, all of the processing and dewatering considerations discussed above (i.e., dewatering technologies, staging areas, and water management) will not be retained during assembly and selection of the IM alternative.

Final Disposal

Implementation of dredging is usually more complex and costly than other remedial technologies based on the need to dispose of the dredged material and comply with specific disposal requirements. The United States Army Corp of Engineers- (USACE-) operated Pointe Mouillee CDF is currently anticipated for final sediment disposal. The CDF is located 8 miles downstream near the town of Rockwood, Michigan. The CDF has an access channel from the Federal Channel to the facility's unloading dock that is four miles long, 200 feet wide and 165 feet in depth. Materials would be offloaded and transported to a disposal compartment (cell) within the CDF by general construction equipment.

The advantages of disposal at the pre-selected facility via barge transport include: dewatering prior to disposal would not be required, risks associated with materials handling and transport are reduced, Site and community disruption are limited, barge access is available and an area for offloading is provided.

The conceptual design presented herein, and the IM components ancillary to removal, reflect this decision and utilize these disposal assumptions. If disposal at the Pointe Mouillee CDF becomes infeasible, alternate disposal options may be required for consideration during design. These alternate options could include disposal at a regulated landfill, or at a different engineered disposal facility (i.e., confined aquatic disposal cell [CAD]). In some parts of the country, disposal capacity may be limited in existing landfills, thus significantly increasing project complexity and cost and inevitably influencing removal selection.

Removal Technologies Assessment

Selection of appropriate removal technologies and their potential effectiveness for implementation as an IM alternative at the Site was a formulaic effort considering multiple variables ranging from water depth to disposal sites. In general, dredging as an IM alternative may have negative short-term impacts (such as generation of residuals, resuspension of contaminated sediments, and disruption to habitat), however removal of contaminated sediments from the channel bottom can be an important component in the reduction of long-term risks associated with exposure to constituent concentrations within the sediments.

There are several common implementation and efficiency considerations with both dredging approaches, for example, both mechanical and hydraulic removal will:

- Temporarily disrupt the existing aquatic community and habitat within the targeted removal area.
- Require mechanical debris removal prior to sediment removal.
- Potentially result in contaminant loss through resuspension, dissolution, and volatilization resulting in a release of COCs into the water column or air.
- Require setbacks or constraints to protect shoreline structures.
- Require similar design support activities, such as mobilization of dredge equipment, guidance technology used for the accuracy of dredging, transport, processing, offsite disposal, and permitting; as well as operating constraints, such as overhead restrictions, utility setbacks, and narrow channel widths.

Several important distinctions among the two removal methods warrant consideration for applicability at the Site and thus are presented in Table 4-2 for ease of review and comparison. These distinctions are discussed in detail below.

Table 4-2 - Removal General Remedial Options

Screening Criteria	Removal General Remedial Options	
	Mechanical	Hydraulic
Access to Target Materials	Water depth must be sufficient if performed via barge. Land-based operations can be conducted if removal areas are within 50 feet of the shoreline. Surficial debris could be removed prior to, or during, sediment removal.	Water depth must be sufficient for in-water based equipment. Debris must be removed prior to sediment removal.

Screening Criteria	Removal General Remedial Options	
	Mechanical	**Hydraulic**
Effect Due to Shoreline and In-Water Structures	Efficient in constricted/confined areas such as docks and piers as equipment modifications (bucket size) can be implemented to accommodate site conditions. Removal operations are adaptable to land-based operations if shallow water depths are encountered.	Smaller equipment types are capable of working in shallow water depths, but a minimum water depth of 2.5 feet is required (Palermo et al. 2008).
Submerged Debris	Small impact on efficiency.	Substantial impact on efficiency; prior mechanical removal of debris is required. Small debris can plug the dredge head and clog/accumulate in hydraulic pipeline thereby decreasing dredge productivity.
Production	Medium capability for dredging production depending on bucket size, cut depth, bucket fill percentage, and river hydraulics.	High capability for dredging production depending on amount of debris, diameter of pipeline, and water depths.
Resuspension	Moderate resuspension of contaminated sediment, operational controls (i.e., slower production rates) can be implemented to try to reduce sediment resuspension.	Resuspension of contaminated sediment is generally less than that experienced with mechanical techniques.
Additional Passes or Follow-On Activities	Additional passes may be necessary to meet sediment removal criteria.	Additional passes may be necessary to meet sediment removal criteria..

Screening Criteria	Removal General Remedial Options	
	Mechanical	**Hydraulic**
Effect on Project Duration	Equipment size determines project duration.. Reduced processing time due to lower water content.	Installation and maintenance of hydraulic pipeline, encounter of submerged debris during removal, potential for pipeline interference with channel navigation/boat traffic, and management of a large volume of water may increase project duration.
Transportation Options	Efficient for barge transport, but sediments can be offloaded for truck transport as well. Dewatering may be necessary prior to land-based transport of removed materials.	Hydraulically dredged material can be transported via hydraulic pipeline.
Hardpan/Bedrock/Debris Fill	Difficulties in removing overlying sediments.	Difficulties in removing overlying sediments.

Hydraulic removal was not retained beyond this technology screening due to certain limitations of the technology when evaluated against existing Site conditions. Hydraulic dredges generate a large quantity of excess water (carriage water) for sediment conveyance and implementation of this technique would require supplemental design considerations to accommodate the management of large volumes of water. Pipeline conveyance of dredged material for disposal may require booster pumps to maintain sufficient flows to avoid material fallout. Based on the preferred disposal facility, 8 miles of pipeline, several booster pumps, and continual monitoring/maintenance activities would be required to sufficiently convey the material. In addition, the pipeline and pump stations would likely interfere with channel navigation and the high boat traffic within this area. As such, the hydraulic transport of material would not be readily implementable or economically reasonable based on the quantity of sediment scheduled for removal.

Mechanical removal was retained for the development of IM alternatives based on current understandings of the Site and the disposal facility. Mechanical removal is effective in constricted or confined areas such as working adjacent to shoreline structures or in close proximity to boat traffic, both of which are present at the Site. If dredged sediment is to be disposed of at the nearby CDF, the excavated material can be placed directly within a barge for transport to the facility.

One of the areas scheduled for removal at the Site is outside the defined navigation channel and is not frequently navigationally maintained. As such, an abundance of debris exists in the footprint and has been identified during initial review of hydrographic surveys as discussed in Section 2. Removal using either hydraulic or mechanical methods is not expected to be an efficient or effective process due the inability to achieve target removal cutlines. As such, removal was not retained as a viable process option for this area.

Although effective in greatly increasing the removal of constituent concentrations associated with potential risks to human health and the environment, sediment removal as a stand-alone approach often has a limited ability to fully achieve project objectives due to residual sediments. Therefore, mechanical removal will be evaluated as an IM response option in combination with placement of a residuals cover layer.

4.3 Assembly of Alternatives

Technologies and GROs that were retained from Section 4.2 are listed below. These technologies and GROs were carried forward for the development of IM alternatives to address impacted sediments at the Site and include the following:

IM Alternative 1: No Action

IM Alternative 2: Monitored Natural Recovery

IM Alternative 3: Mechanical Removal with Residual Management

IM Alternative 4: Partial Removal and Cap Placement

IM Alternative 5: Targeted Removal with Cap Placement

Alternatives 3, 4, and 5 can be classified as hybrid approaches due to the multiple GROs that have been combined. In addition, these alternatives contain similar construction components including sediment removal via mechanical techniques, installation of resuspension controls, debris removal, structural sheetpile support installation adjacent to Area C, post-removal verification, and material disposal in the Pointe Mouillee CDF. As such, the aforementioned components are only included in the Alternative 3 discussion. Further descriptions of each alternative are provided below.

4.3.1 Alternative 1: No Action

Under this alternative no active remediation or monitoring would be conducted. Therefore, the existing conditions in Site sediment would not change, with the exception of those undergoing natural processes. The No Action alternative is generally appropriate in situations where contamination at a site presents no current or potential threat to human health or the environment, or when a previous response action has eliminated the need for additional remedial action. Alternative 1 is not being considered for implementation at the Site, but rather is being presented for comparison with the other IM alternatives to identify baseline environmental conditions in the absence of remediation.

4.3.2 Alternative 2: Monitored Natural Recovery

Under this alternative, no active remediation activities would be conducted. Improvements in the area and progress toward the IM objectives would depend on natural recovery processes ongoing in the project footprint. Current understanding of the Site provides evidence that ongoing geochemical transformations currently contribute to reduction in surface sediment exposure levels, for example bulk sediment pH levels at the southern portion of the Site. Further evaluations and investigations would be required to provide a better understanding of additional and ongoing MNR processes. This alternative would include implementation of a long-term monitoring program to confirm the occurrence of natural processes and the reduction of potential risk and ecological exposures. Furthermore, long-term monitoring would focus on expanding Site knowledge of chemical and biological trends in the channel. Monitoring requirements are defined in a project specific long-term monitoring plan during remedy design but typically include a pre-defined monitoring duration. Long-term monitoring would likely be conducted for multiple media including the sediments, water column, and biota – although benthic toxicity monitoring is a likely monitoring endpoint of interest for North Works.

4.3.3 Alternative 3: Mechanical Removal with Residual Management

Alternative 3 consists of sediment removal and placement of a residuals cover layer. The specific components of Alternative 3 include: (1) sediment removal from Areas B, D, and F within the federal navigation channel; (2) sediment removal from Areas A, C, and portions of Area E (E-1 and E-2) located adjacent to the dock structure and rip-rap shoreline; and (3) placement of a residuals cover layer in Areas A, C, and portions of Area E. The project footprint depicting the locations of specific management units for Alternative 3 (Areas A through F) are presented in Appendix D, Figure 1.

A resuspension control system would be installed prior to any intrusive sediment work to minimize potential migration of suspended material to surrounding areas. Debris removal activities would commence following the installation of resuspension controls followed by sediment removal.

All sediment under this alternative would be removed via barge mounted mechanical techniques. The total dredge area (Table 4-3) footprint is approximately 5.7 acres containing locations within the navigation channel (3.0 acres), adjacent to the existing dock structure (2.2 acres), and Areas E-1 and E-2 (0.5 acres). The average removal depth in the navigation channel is 4 feet while the dredge areas adjacent to the shoreline are approximately 5 feet (Area C) and 5.3 and 6.6 (Areas E-1 and E-2, respectively). The total volume scheduled for removal under this alternative is approximately 40,600 cubic yards (cy) and does not consider side slopes in total quantities. Dredge volume estimates would be revised during design once dredge delineation boundaries, shoreline offset requirements, and site characteristics are fully evaluated. All sediment targeted for removal within the navigation channel would be removed to native clay to support and accommodate commercial/industrial navigation traffic. Based on existing hydrographic surveys, debris removal is anticipated to be minimal in the navigation channel and significant near the shoreline and would be performed via mechanical means prior to sediment removal operations.

To support removal activities in Area C, sheet piling would be driven to provide structural support for the existing dock structure and maintain slope stability during removal activities. The sheeting is anticipated to be approximately 400 linear feet and driven 60 feet to native clay. Final sheet pile design would be dependent upon the additional evaluations that will be conducted subsequent to the data gap investigation detailed in Section 5. Areas A and E do not require structural support as the remedial area does not extend to the existing dock structure.

Real-Time Kinematic Digital GPS (RTK-DGPS) mounted on the dredge equipment, as well as bathymetric surveys, would be used to verify that specified removal depths are achieved. The bathymetric surveys would be conducted following removal activities to confirm achievement of cutlines and whether additional removal may be required. Placement of a 6-inch thick sand residuals cover layer would be conducted upon verification of dredge cutline in the dredge area adjacent to the dock structure. Approximately 2,200 cy of sand for the residuals cover layer would be required for placement under this alternative. No materials would be placed within the navigation channel.

Removed sediments would be transported offsite via barge transport to the Pointe Mouillee CDF for final disposal. Dredged material would be placed in the CDF in a manner that is protective of human health and the environment, and material placement would meet applicable and promulgated State water quality standards, as well as any other applicable Federal/State environmental laws and regulations. Dewatering of sediments or other processing activities is not anticipated prior to placement within the CDF.

4.3.4 Alternative 4: Partial Removal and Cap Placement

Alternative 4 consists of sediment removal and capping as detailed in Table 4-3. Specific components of Alternative 4 contain the following: (1) sediment removal in Areas B, D, and F within the federal navigation channel; (2) sediment removal in Area C located adjacent to the dock structure; (3) partial removal of sediment in Areas A and E to accommodate the placement of an engineered isolation cap; (4) placement of an engineered isolation cap in Areas A and E; and (5) placement of a residuals cover layer over Area C. See Appendix D, Figure 2 for location of remedial areas and project footprint.

Under this alternative, all sediment would be removed via barge-mounted mechanical techniques. The total dredge area footprint is approximately 8.4 acres containing locations within the navigation channel (3.0 acres) and adjacent to the existing dock structure and rip-rap shoreline (5.4 acres). The average removal depth in the navigation channel (Areas B, D, and F) is 4 feet, the dredge area adjacent to the shoreline (Area C) is 5 feet, and Areas A and E would target partial sediment removal to a depth of 2 feet to accommodate the placement of the engineered isolation cap. The total volume targeted for removal under this alternative is approximately 41,400 cy and does not consider side slopes in total quantities. Dredge volume estimates would be revised during design once an updated understanding of dredge delineation boundaries, shoreline offset requirements, and site characteristics are fully evaluated. All sediment scheduled for removal within the navigation channel would be removed to native clay to support and accommodate commercial/industrial navigation traffic. Achievement of specified removal depths would be verified as discussed in Alternative 3.

All cap materials under this alternative would be placed via barge mounted mechanical techniques. The total cap/backfill footprint is approximately 5.4 acres containing placement of a residuals cover layer in Area C (1.0 acre) and engineered isolation cap placement in Areas A and E (4.4 acres). Placement of a 6-inch thick residuals cover layer would be conducted upon verification of dredge cutline in Area C, the removal area adjacent to the dock structure. In addition, a 2-foot thick isolation cap would be installed over areas A and E, located adjacent to the dock structure. Placement of an isolation cap is anticipated to provide the appropriate protection from constituent concentrations within impacted sediments. From bottom to top, the isolation layer would consist of a 1-foot sand layer, a geotextile, and a 1-foot armor layer, resulting in a total cap thickness of 2 feet. The material volumes targeted for placement under this alternative is approximately 800 cy of sand for the residuals cover layer and 7,100 cy of sand (isolation layer) and 10,700 tons of stone (erosion control layer) for the engineered isolation cap. No cap materials would be placed within the federal navigation channel. Materials specifications would be selected, and cap transitions determined, following additional geotechnical evaluation conducted during remedy design.

4.3.5 Alternative 5: Targeted Removal with Cap Placement

Alternative 5 consists of sediment removal and capping as detailed in Table 4-3. Specific components of Alternative 5 include the following: (1) sediment removal from Areas B, D, and F within the federal navigation channel; (2) sediment removal in Area C located adjacent to the dock structure to a designed elevation template; (3) placement of an engineered isolation cap in Areas A and E located adjacent to the dock structure and rip-rap shoreline; and (4) placement of a residuals cover layer within removal Area C. Alternative 5 differs from Alternative 4 as it does not require partial removal prior to placement of the engineered isolation cap. However, similar to Alternatives 3 and 4, a resuspension control system would be installed, debris removal activities would be conducted, and sheet piling would be driven in Area C prior to the commencement of any intrusive sediment activities.

All sediment under this alternative would be removed via barge mounted mechanical techniques. The total dredge area footprint is approximately 4.0 acres containing locations within the navigation channel (3.0 acres) and adjacent to the existing dock structure (1.0 acre). The average removal depth in the navigation channel (Areas B, D, and F) is 4 feet while the dredge area adjacent to the shoreline (Area C) is 5 feet. The total volume targeted for removal under this alternative is approximately 27,000 cy and does not consider side slopes in total quantities. Removal volume estimates would be revised during design once dredge delineation boundaries, shoreline offset requirements, and Site characteristics are fully evaluated. All sediment targeted for removal within the navigation channel would be removed to native clay to support and accommodate commercial/industrial navigation traffic. Achievement of specified removal depths would be verified as discussed in Alternative 3. Cap placement would be conducted as detailed in Section 4.3.4 for Alternative 4.

4.4 Comparison of IM Alternatives

This section evaluates and compares criteria discussed in Section 4.1 for the five IM alternatives described in Section 4.3. The evaluation process presented in this section is consistent with the CAP guidance (USEPA 1994b) and RCRA requirements. A detailed summary of this evaluation is provided in Table 4-4.

4.4.1 Protect Human Health and the Environment

Alternative 1, No Action, may not be protective of human health and the environment as no control of exposure to impacted sediments is provided and existing risks are not verifiably reduced – except as by natural processes and watershed source controls. Verification of these changes over time is not possible without monitoring.

Natural recovery processes (chemical, physical, and biological) have the potential to reduce risks over time, but Site-specific processes require additional investigations or are currently unknown and the timeframe for these processes to achieve the cleanup standards and project objectives cannot be determined. Therefore, limited protection to human health and the environment would be provided by Alternative 2.

Sediment removal activities to be conducted as a component of Alternatives 3, 4, and 5 may temporarily increase exposure risks as a result of the resuspension of COCs and the generation of residual sediments. However, resuspended and residual sediments would be reduced under each of these alternatives by implementation of necessary engineering and operational controls during construction and placement of a residuals cover layer subsequent to removal. These controls would likely limit the exposure to potential receptors and the potential for downstream migration of COCs. Thus, protection provided by Alternatives 3, 4, and 5 would ultimately rely on the accuracy of the selected dredging equipment and operational controls to limit sediment resuspension and the effectiveness of the remedial components to manage residuals and/or sediment isolation. The IMs to be conducted under Alternatives 3 and 4 would both provide additional protection from exposure to the COCs via sediment removal.

Alternative 3 requires the removal of approximately 40,600 cy of impacted sediment from the Site, whereas Alternative 4 requires an additional 800 cy (approximately 41,400 cy total). The additional removal volume is a result of sediment removal scheduled within Areas A and E, which exhibit low level concentrations. The additional volume scheduled for removal under Alternatives 3 and 4, in comparison to Alternative 5, may result in an increase in sediment resuspension and thus could increase the potential for human exposure and may pose additional impacts to the water quality and ecological habitat.

Alternative 5 would ultimately provide greater protection than Alternatives 3 and 4 from the impacted sediments located in Areas A and E as removal would not be conducted prior to placement of the engineered isolation cap and the likelihood of exposure due to increased sediment disruption is reduced.

4.4.2 Attainment of Cleanup Goals

Alternative 1, No Action, would not verifiably attain the sediment cleanup standards as potential changes due to natural processes would not be monitored under this alternative.

Natural processes occurring at the Site are not clearly understood at this time; therefore, attaining the cleanup standards via implementation of Alternative 2 cannot be fully assessed.

Alternatives 3 through 5 are anticipated to achieve the cleanup standards as implementation of each of the IM alternatives would result in the reduction of constituent toxicity within the locally impacted sediments, relative to upstream levels, and bioavailability to ecological receptors. Implementation of a long term monitoring plan as a component of these alternatives will monitor the achievement of cleanup goals and verify that project objectives are being met.

4.4.3 Control the Sources of Releases

As described in Section 2, significant upstream contaminant sources and sediment inventories have been documented within the Trenton Channel. These upstream sources are currently not controlled. As the intent of this IMDWP is to identify an IM alternative of the complete remedial scope, no source control would be provided by any of the alternatives considered herein. Thus, areas addressed as a part of the selected IM alternative would be subject to future recontamination.

4.4.4 Compliance with Applicable Waste Management Standards

With exception to Alternative 1 (No Action) each IM alternative (Alternatives 2 through 5) would comply with applicable waste management standards. This criterion is not applicable to the No Action alternative as no wastes would be generated. The types of wastes that are anticipated as a result of implementation of Alternatives 2 through 5 include sediments removed from the channel bottom during monitoring and removal activities; general refuse from construction activities and Site development debris; debris removed prior to cap placement and sediment removal; and any wastewater generated during implementation of the IM alternative, monitoring, or decontamination of equipment. Disposal of these wastes is anticipated to occur at the USACE-operated Pointe Mouillee CDF, as discussed in Section 4.2.5.2. The facility operations and disposal cell construction (if necessary) will be conducted in accordance with BMPs, accepted engineering techniques and applications, and applicable federal regulations.

4.4.5 Long Term Reliability and Effectiveness

With the exception of Alternative 1, all of the IM alternatives would be expected to provide some degree of long term effectiveness by mitigating the potential for human or ecological exposure to Site-related COCs. It is anticipated that MNR has the potential to reduce risks; however, an extended period of time (currently unknown) may be required to achieve cleanup levels and project objectives, thus Alternative 2 cannot be relied upon on to be effective in the short term.

For Alternatives 3, 4, and 5, long term effectiveness would rely upon the limitations associated with the mechanical dredging equipment utilized, the engineering and operational controls implemented during construction, the rate and magnitude of future deposition and potential for natural recovery, and the stability of the residuals management and engineered isolation layers. A reduction in sediment resuspension resulting from construction activities and residual sediment exposure would make each alternative more effective in the long term. Alternatives 3, 4, and 5 would remove in-situ contaminant concentrations, and if implemented successfully, would require minimal future maintenance activities with exception to cap monitoring and maintenance (for Alternatives 4 and 5).

Ultimately, long term effectiveness of the IM alternatives to achieve cleanup standards and project objectives would be evaluated through implementation of a long term monitoring program. However, by removing impacted sediment from the environment and providing physical long term isolation and sequestration of COCs within the sediment, Alternatives 3, 4, and 5 would provide a high degree of long term reliability and effectiveness.

4.4.6 Reduction in the Toxicity, Mobility, or Volume of Wastes

Alternative 1 does not reduce the toxicity, mobility, or volume of Site-related COCs because no action would be implemented.

Alternative 2 does not readily provide reduction of toxicity or volume, although in the long term this alternative could provide reduction of constituent concentrations and bioavailability as a result of natural recovery processes. However, Site-specific processes are not clearly understood at this time due to insufficient data.

Alternative 3 would effectively reduce constituent toxicity and volume by removing a significant volume of contamination, but in the short term would increase the mobility of constituents within the sediments as a result of surface sediment mixing, resuspension, and exposure of residual sediments to the overlying water column. To reduce the potential for migration and water quality impacts during removal activities, a resuspension control system would be designed and constructed and equipment operational controls will be implemented to minimize water quality impacts. In addition, residual management would be provided by Alternative 3 to reduce the mobility of residuals in the short term.

Alternatives 4 and 5 would also have the short term sediment mobility implications inherent with dredging activities as described for Alternative 3; however, these alternatives would address constituent toxicity, mobility, and volume within Areas A and E through the placement of a long term engineered isolation cap. For Alternative 4, additional removal is scheduled within Areas A and E to accommodate placement of the engineered isolation cap. This approach provides additional reduction in contaminant toxicity and volume; however, mobility of the COCs may increase as a result of an increase in resuspended sediments. Conversely, Alternative 5 would not reduce the toxicity or volume through active remediation in Areas A and E as no additional removal would be conducted to accommodate the thickness of the engineered isolation cap; however, mobility would be reduced as additional removal of impacted sediment would not be conducted.

Sediments removed under Alternatives 3, 4, and 5 evaluated herein are anticipated to be disposed of at the Pointe Mouillee CDF. The facility is governed by the USACE and the facility operations and disposal cell construction (if necessary) would be conducted in accordance with BMPs, appropriate engineering applications, and applicable federal regulations. As such, the mobility and toxicity of the material following placement would be protective of human and ecological receptors. In addition, sediment dewatering and treatment (i.e., stabilization) may be conducted to achieve disposal requirements which would reduce leachability and mobility of contamination; however treatment is not currently anticipated.

4.4.7 Short term Effectiveness

Alternative 1 would not mitigate existing risks, but would not pose any additional risk to the community, construction workers, or the environment.

Similarly, Alternative 2 would not immediately mitigate existing risks (although it would in the long term).

Alternatives 3 and 4 provide immediate reduction in contamination via sediment removal as well as temporary isolation to residual sediments by placement of a residuals cover layer subsequent to sediment removal for Alternative 3 and placement of a residuals cover layer and engineered isolation cap for Alternative 4; however, temporary impacts inherent to sediment removal activities could result in increased risks in the short term due to increased resuspension and greater potential for exposure and disturbance to the ecological habitats and aquatic environment. The degree of impacts generated from removal activities is dependent upon the accuracy and capability of the equipment and operator used for removal; the effectiveness of the operational and engineering controls implemented to reduce surface sediment mixing and sediment resuspension; and the rate and magnitude of deposition occurring within the channel on newly exposed material. Impacts inherent to in-water construction activities include a temporary decrease in water quality and disruption to the aquatic environment. However, placement of an engineered isolation cap for Alternative 4 allows for opportunities to provide suitable environment for habitat reconstruction and enhancement will likely be available during cap placement.

Alternative 5 would result in similar short term impacts as Alternatives 3 and 4; however, Alternative 5 would require a smaller removal volume (approximately 14,400 cy less than Alternative 4 and 13,600 cy less than Alternative 3) and provide isolation to sediments within Areas A and E, as opposed to removal, given the lower-level concentrations within these areas. Placement of an engineered isolation cap over Areas A and E would immediately provide protection to short and long term exposure risks associated with impacted sediments, and will likely provide for habitat reconstruction and enhancement opportunities. Immediate protection within Areas A and E is not provided by Alternatives 3 or 4, thus Alternative 5 is most effective within the short term.

4.4.8 Implementability

Alternative 1 is not applicable to this discussion as no IM alternative would be required for implementation. Overall, Alternatives 2 through 5 are all readily implementable. No implementability concerns are associated with Alternative 2 as activities would be limited to monitoring (i.e., the collection of surface water and sediment samples) and additional Site evaluations. However, for Alternatives 3, 4, and 5, certain Site conditions may require additional consideration and engineering prior to implementation. For example, debris exists within the targeted removal area which requires removal prior to implementation of the IMs specified for Alternatives 3 through 5. In addition, existing shoreline conditions and the stability of existing bank structures would be of concern for removal setbacks, the need for additional stability measures, and the transition for placement of the engineered isolation cap with the shoreline/bank structures.

Ease of implementability and the specific components of Alternatives 3, 4, and 5 would have an effect on the overall project duration, which in turn affects project costs (as discussed in detail in Section 4.4.9). Due to the additional removal volume required by Alternatives 3 and 4 (approximately 13,600 and 14,400 cy, respectively) in comparison to Alternative 5 and the placement of an engineered isolation cap over 4.4 acres for Alternative 4 (as opposed to a residuals cover layer for Alternative 3), complete implementation of these alternatives may require multiple construction seasons and thus multiple mobilization/demobilization events. Therefore, implementability of Alternative 3 and 4 is less desirable as a result of the increased footprint size (i.e., additional shoreline considerations, increased aquatic disruptions) and increased project duration (i.e., multiple construction seasons, availability of equipment for prolonged duration), which in turn increase project costs. However, based on removal and capping volumes identified for Alternatives 5, there is potential for remedy implementation to be completed within one construction season. Project completion within one season would greatly reduce project costs due to only one required mobilization/demobilization event and by reducing the duration of equipment rental. Therefore, Alternative 5 is the most implementable IM alternative.

4.4.9 Cost

A detailed cost evaluation for each of the IM alternatives is presented in Appendix D. A summary of these costs are provided within the table below and discussed herein.

Table 4-5 –Comparison of Interim Measure Alternative Costs

Alternative ID	Cost
Alternative 1	$0
Alternative 2	$1.1M
Alternative 3	$8.5M
Alternative 4	$9.9M
Alternative 5	$7.7M

Notes:
(1) See Table 4-3 for Alternative components including removal areas, removal and residual cover layer volumes and capping quantities (isolation and armor).
(2) M = million

No costs are associated with Alternative 1 as no IM would be implemented under this alternative. In addition to Alternative 1, Alternative 2 would be the least expensive alternative to implement as this alternative would only require monitoring and continued Site evaluations. The total cost estimated for implementation of Alternative 2 is approximately $1.1M. For Alternative 3, the total cost estimate for implementation is approximately $8.5 M. Additional costs within Alternative 3 account for the removal of sediments within Areas A, B, C, D, F, and portions of Area E and the placement of a residuals cover layer within Area A, C and portions of Area E. The total cost associated with implementation of Alternative 4 is approximately $9.9M. Costs considered within Alternative 4 are similar to those within Alternative 3; however, the increased cost for implementation of Alternative 4 accounts for the placement of an engineered isolation cap within Areas A and E, as opposed to a residuals cover layer. The total cost associated with implementation of Alternative 5 is approximately $7.7M. The total cost of Alternative 5 is less than Alternatives 3 and 4 as Areas A and E are not scheduled for removal prior to placement of the engineered isolation cap or residuals cover layer, which reduces overall project costs by approximately $0.8 M and $2.1M, respectively.

4.5 Selection of Interim Remedial Measure

Based on the comparative analysis provided in Section 4.4, as summarized within the table below, Alternative 5, Targeted Removal with Cap Placement has been tentatively selected as the IM alternative for the Site. This alternative is subject to revision or refinement upon data collection as described in Section 5 – and through conduct of the actual design work.

Implementation of this alternative effectively addresses eight of the nine evaluation criteria, the only exception being source control. Potential sources include recontamination from upstream; thus, source control is not provided by any of the alternatives considered herein, as each alternative deals solely with sediments located adjacent to the Site and not with upstream impacts. Upstream impacts will continue, which is an important reality with respect to selection of a sustainable approach that is not reversed by recontamination.

Table 4-6 - Comparative Evaluation of Interim Measure Alternatives

Evaluation Criteria	IM Alt. 1	IM Alt. 2	IM Alt. 3	IM Alt. 4	IM Alt. 5
Protect Human Health and the Environment	○	◑	◑	◑	●
Attainment of Cleanup Goals	○	NA	●	●	●
Source Control	○	○	○	○	○
Compliance with Applicable Waste Management Standards	○	●	●	●	●
Long term Reliability and Effectiveness	○	NA	●	●	●
Reduction in the Toxicity, Mobility, or Volume of Wastes	○	NA	◑	●	●
Short term Effectiveness	○	○	◑	◑	●
Implementability	NA	●	◑	◑	●
Cost	NA	NA	NA	NA	NA

Notes:
1. See Section 4.3 for a description of the Alternatives.
2. NA - Cannot be assessed.
3. ○ - Does not meet evaluation criteria.
4. ◑ - Partially meets evaluation criteria.
5. ● - Fully meets evaluation criteria.
6. Refer to cost comparisons provided in Section 4.4.9 as they cannot be qualitatively compared to required criteria

Alternative 5 is the most efficient and effective at attaining Site cleanup standards and achieving the identified project objectives, as described in the previous sections. This alternative utilizes a hybrid approach that combines sediment removal and cap placement, as depicted on Figure 4-1; and includes:

- Removal of 18,500 cy from the Trenton Federal Channel (Areas B, D, and F).
- Removal of 8,500 cy of sediment identified for removal from areas adjacent to the dock structure (Area C).

- Placement of a 6-inch residuals cover layer within Area C.
- Placement of a 2-foot engineered isolation cap over sediments located within Areas A and E (approximately 4.5 acres).

The estimated cost to implement the selected IM alternative is approximately $7.7M. Assumptions used in the development of cost estimates are provided in Appendix D.

Implementation of Alternative 5 will provide a high degree of overall protection to human health and the environment; will achieve cleanup goals by reducing bioavailability to the benthic community through the removal of impacted sediment (Areas B, C, D, and F), placement of a residual cover layer within Area C to address residuals, and a 2-foot thick engineered isolation cap to sequester sediments containing lower-level constituent concentrations (Areas A and E); provides a high degree of long term reliability and effectiveness; has been successfully utilized and implemented in many similar environments; and can be completed in a reasonable timeframe.

This alternative will result in short term impacts due to sediment resuspension inherent with dredging activities; however, the extent of remobilization is minimized relative to other removal alternatives and the implementation of engineering and operation controls will reduce such impacts. Temporary disruption to the existing aquatic environment will occur; however, opportunities for habitat reconstruction and enhancement are anticipated through residual cover and engineered cap modifications. Placement of the isolation layer will reduce the water depth in Areas A and E but is not anticipated to affect navigation and boat traffic in the area. Initial assessments indicate that an average water depth of approximately 21.7 feet following the construction of caps in Areas A and E. Similar projects in scope, such as the Fox River, only required a final water depth of 3 feet (USEPA 2003). Vessels with significant drafts remain within the federal navigation channel where no cap placement is proposed and thus will not be impacted by decreased water depths. Also, reduced water depths as a result of cap placement are not expected to impact flood storage capacity within the channel.

Access to the Site for equipment and cap material transport is attainable via land- or water-based transportation. Site development activities and thus restoration activities will be minimal as sediment does not require staging or dewatering prior to disposal. Coordination to schedule available construction equipment will be necessary for the installation of sheet piling, removal of sediments, placement of cap material, and transport of removed sediments to the Pointe Mouillee CDF by barge. Transport of sediments via barge will limit rehandling of materials, allow for efficient production rates, and eliminate the need for sediment processing and land-based transportation logistics. No known obstructions (i.e., dams, reduced water depths) along the barge transport route to the Pointe Mouillee CDF are anticipated. In addition, barge docking and sediment offloading areas are available at the disposal facility.

It was determined that Alternative 5 best achieves project objectives and balances the criteria used to evaluate each alternative in accordance with RCRA guidance (USEPA 1991), as presented in Table 4-4 and Table 4-6, and thus selected as the most appropriate IM alternative for implementation at the Site.

4.6 Achievement of Interim Measure Objectives

Site-specific objectives were previously identified in Section 3.1. Individual components of the selected remedy were established to achieve project objectives as detailed below.

- Protection of the benthic community in areas of known or potential ecological impairment or toxicity.

Sediment containing the highest mass contamination (Area C) will be removed followed by the placement of a residuals cover layer. Removal of targeted sediment in Area C will reduce overall impacts to the benthic community while the residuals cover layer will provide immediate reduction of residual contamination in addition to providing the opportunity for habitat for benthic community re-establishment. All impacted sediment will be removed from Areas B, D, and F, and an isolation cap constructed in Areas A and E will provide isolation and protection for the benthic community. Installation of the isolation cap will also provide an opportunity to enhance the benthic habitat. These activities will protect the benthic community from known ecological impairment or toxicity.

- Sustainable benthic community risk reductions that are not reversed by recontamination by ongoing sources.

Sediment containing high contaminant mass will either be removed (Areas B, C, D, and F) or isolated (Areas A and E). Post-construction monitoring of the capped areas will be performed to verify that the cap is functioning as designed, has successfully isolated impacted sediment, and reduced the risk of recontamination from remaining impacted sediment. The residuals cover layer installed in Area C will serve to provide immediate reduction in residual contamination, although the residual sediment is not expected to contain a significant containment mass. Impacted sediments located in Areas B, D, and F will be removed to native clay. These activities will minimize the risk of recontamination by onsite sources.

As stated above, upstream sources cannot be controlled by the selected IM alternative. Impacted material may return to the Site via sediment deposition in the river. However, contaminant concentrations in deposited sediment are not expected to exceed BSLs in the river.

- Minimization of short term effects of construction.

The selected IM alternative is anticipated to be completed within one construction season. Short term effects to water quality due to sediment resuspension will be minimized using engineering and institutional controls including, but not limited to, resuspension controls and monitoring, equipment and operational controls, and minimizing material rehandling. Local truck traffic will include transportation of personnel and equipment. Capping material may also be delivered via trucks if barging is determined infeasible. No removed sediment is anticipated to be shipped by trucks; rather it will be shipped via barge to the Pointe Mouillee CDF.

- Ensure that adequate access to the shoreline is maintained for barge traffic and anticipated future uses.

No significant impacts to shoreline use are anticipated. Sediment removal in Area C will remove contaminant mass while providing additional navigational draft. The installation of an isolation cap (2 feet in thickness) will increase the bathymetric elevation in Areas A and E, but will still accommodate anticipated vessel size and traffic. Shoreline stability will be of critical importance during the design of the selected IM alternative. Design considerations will be evaluated and implemented to ensure that the stability of the shoreline is not compromised and current activities in the area can be successfully completed.

5. Interim Measure Design Data Needs

Various data will be required as part of the project design outlined in this IMDWP and include those summarized below.

Confirmation of Bioassay Findings, Characterization of In-situ Toxicity – A sampling plan for in-situ bioassays will be prepared that will identify the number of samples, the test species, the number and length of deployments, and the measurement endpoints. Exposure concentrations will be measured from sediment and pore water samples taken at each of the bioassay sampling stations. The analyte list will be guided by results from the existing bioassay and benthic community assessment findings. The purpose of this sampling will be to better establish the relationship between bulk sediment pH and benthic community health, and/or selecting a more appropriate pH measurement endpoint and value for site management. The results will be used to reassess, and if appropriate, refine the project boundaries and/or other aspects of the proposed alternative.

Characterization for Disposal – Composite samples for disposal characterization will be collected from approximately 10 sediment cores within the project area. The composite samples will be submitted for Toxicity Characteristic Leaching Procedure (TCLP) analysis to assist in disposal evaluation.

Disposal Facility Identification – It is currently anticipated that the CDF located at Point Mouillee will be used for disposal of sediment removed from the site. Discussions will be held with the CDF to confirm available space and acceptability of the material. Identification of alternative disposal facilities will also be required if CDF disposal does not prove to be a viable option.

Geotechnical Properties – Geotechnical characterization will be required for sediments located within the project footprint. Geotechnical investigations will be conducted to provide subsurface data to support future design components of the selected IM alternative including the collection of samples which may be tested for various properties such as Atterberg limits, grain size distribution, moisture content, specific gravity, triaxial shear, and bulk density. An ARCADIS geotechnical engineer will provide full-time oversight of the investigation and a subcontractor will provide the drilling services. The field personnel will also document the subsurface characteristics of each boring advanced during geotechnical investigation activities. The results of the investigations will be reviewed, evaluated, and incorporated into future design activities.

Utility and In-Water Structures Survey – An investigation will be completed to identify locations where project activities such as borings, sediment removal, or other intrusive activities could conflict with utility or pipe lines. Relevant records and maps for the area will be acquired and reviewed, and side-scan sonar and magnetometer survey data will be reviewed. Property owners, including BASF, will be contacted and interviewed for information concerning installations on their property, as appropriate. Following the information review and interviews, geophysical surveys utilizing ground penetrating radar or electromagnetic techniques will be employed, as needed, along the shoreline by watercraft to identify the specific locations where utilities or pipelines enter the river.

Debris Identification – Detailed hydrographic survey and side-scan sonar information is available for the area adjacent to the Site (ARCADIS 2010). A detailed analysis of these data to identify locations and types of debris on the river bottom will be conducted as part of the design.

Cap Performance Testing – Cap performance bench scale testing and design will be performed to provide confidence that the capping portion of the project will achieve the objective of controlling pH at the interface between the cap and the surface water. The parameters to be tested include the performance of selected capping materials to resist erosive forces and attenuate constituents of concern, including pH. In addition, the possible consolidation and settlement of the sediments to be capped and the proposed cap materials will be evaluated.

Hydrodynamic Modeling – A two-dimensional hydrodynamic model (RMA2) has been developed for the St. Clair – Detroit River Waterway. This model has recently been refined by ARCADIS for the Site area (BBL 2006), however, in order to assist in evaluation, design, and permitting of the selected IM alternative and potentially habitat restoration projects, it may be necessary to make further refinements to the model.

Habitat Characterization and Delineation – An assessment of aquatic habitat type and quality will be completed as necessary to supplement existing information in order to identify and design appropriate habitat improvements. Detroit River natural resource managers will be consulted in the identification and selection of appropriate habitat improvement projects. Any such projects selected will then be incorporated in the design.

6. Basis of Design

6.1 Scope and Summary

This section presents the technical basis of design for the selected IM alternative. The basis of design essentially identifies the requirements that the design must satisfy and constraints on the design. The basis of design is subject to refinement through results of data gap investigations and additional design activities. The selected IM alternative has been divided into key elements for purposes of this section:

- Removal, including sediment processing, and residuals management
- Debris Management
- Utility and Structure Clearances
- Resuspension Controls
- Management, Transportation, and Disposal of Dredged Material
- Capping areas and performance
- Stability of Shoreline Structures
- Habitat Reconstruction and Enhancement

6.2 Sediment Removal

The basis of design for removal includes the following:

- Four primary removal areas, all of which involve removal at depths and distance from shore such as to require barge-based removal operations.
- The volume to be removed is approximately 27,000 cy in water depths up to approximately 39 feet.
- Debris conditions, anticipated transport method (barges), and disposal location (Pointe Mouillee CDF) suggest that mechanical dredging may be the most

appropriate removal method. Mechanical removal has therefore been selected as a design basis.

- Environmental time constraints have been established for in-water construction activities. These time constraints allow in-water work from approximately September through ice formation. This available work schedule is incorporated as a design basis.

- Staging areas are presumed to be on shore at the North Works facility.

6.3 Debris Management

The basis of design includes management of debris in work areas so as to avoid unacceptable complications from debris in implementing the IM. This could include interference with removal or placement of materials – as well as interference with dewatering and management of these materials once removed. Extensive debris is known to be present from hydrographic survey maps. These debris maps will be refined as described in Section 5 - Design Data Needs and incorporated in the design basis.

It is assumed large debris will be removed and managed separately from dredged material. This large debris is expected to be staged onsite and disposed at a commercial facility.

6.4 Utility and Structure Clearances

As detailed in Section 5 – Design Data Needs, utilities and structures within the construction footprint will be located and marked during the design phase. The basis of design will include identification of utility/structure locations to ensure the safety of Site personnel and utilities/structures. Specific procedures will be identified in the design where it is apparent that conflicts may occur between the proposed remedy and utility and structure locations.

6.5 Resuspension Controls

The basis of design for resuspension controls includes the following:

- Provide for turbidity barriers and/or a removal operations approach that will satisfy permit requirements for water quality monitoring and protection during construction operations (See Section 8 – Required Permits). Turbidity barriers will be subject to the following requirements:

- Must withstand river currents where deployed. These velocities are anticipated to be established by hydrodynamic modeling during design.
- Must be structurally stable where deployed. This may be dependent on the characteristics and thickness of river bed materials for anchoring of selected structures.
- Must avoid unacceptable risks of impact to in-river structures.

- Provide for practical and efficient monitoring and maintenance/repair of the controls during the project as needed to comply with permit conditions (See Section 8 – Required Permits) for turbidity.
- Provide for access to and from work areas during construction.

6.6 Management, Transportation, and Disposal of Dredged Material

The transportation of dredged material for the selected IM alternative involves the movement of dredged sediment from the point of origin to the point when the material barges are docked at the offloading facility. It is anticipated that material will be disposed of at the Pointe Mouillee CDF. Dredged material will be transported by barge approximately 8 miles upstream from the Site to the disposal facility.

The specific bases for the dredged material management transport design include:

- On-shore staging of removal operations.
- Ultimate disposal at Pointe Mouillee.

The established chemical characteristics of the sediment will directly determine whether the dredged material is suitable for disposal in the CDF. This determination may also affect any processing which must be conducted to meet specified criteria. If criteria cannot be met, additional disposal options must be considered such as landfill disposal, onsite disposal, incineration, etc. Any additional disposal options would be considered as basis of design and the design approach refined.

The refinement of sediment requiring disposal will drive other aspects in the disposal component of the selected IM alternative. The components include the determination of offloading capabilities (equipment and personnel), infrastructure improvements at the offloading facility, and CDF volume that will be required for disposal. Furthermore, if additional CDF volume is required, the construction of a sub-cell in the existing CDF may be necessary to accommodate the volume of material scheduled for removal.

6.7 Capping Areas and Performance

The basis of design for the cap includes the following primary elements:

- Engineered isolation cap consisting of the following layers:
    - An initial mixing layer placed over existing sediment.
    - An isolation layer consisting of granular soils or sediments to separate impacted material from the water column (other reactive aspects of isolation layer, if any, will be evaluated during design).
    - A geotextile layer (if required) prior to placement of armor layer.
    - An armor layer to resist hydrodynamic forces.
    - A benthic habitat layer (optional and may be incorporated with the armor layer).
- Bioturbation depth is conservatively assumed to be 6 inches.
- Stability on isolation cap by incorporating side slopes of a maximum of 33 percent.
- Stability of the isolation cap under design shear stresses for wind waves, vessel wakes, navigational prop scour, and Detroit River design flow conditions (design flow conditions to be selected during design).
- Monitoring to show effectiveness of the isolation cap with respect to achieving pore water pH levels at the sediment-water interface of less than or equal to 9.

- Provision for acceptable recreational navigational depths (to be determined in design).

Additional amendments to the cap, such as a water-impermeable barrier, pH-reducing amendment, or habitat enhancing layer will be considered during design.

6.8 Stability of Shoreline Structures

The basis of design includes protection of the stability of shoreline structures. For example, removal operations cannot destabilize the dock area and construction activities cannot adversely impact outfall structures currently in use, or mooring structures currently in use along the shoreline. This includes the dock structures, outfalls and intakes, upland structures (fencing, piping, Site controls) that are maintained as part of ongoing Site security and operations for the chemical manufacturing facility (and subject to Department of Homeland Security limitations and requirements). These structures will be identified during design, and appropriate measures will be designed and implemented for protection.

6.9 Habitat Reconstruction and Enhancement

The habitat reconstruction and enhancement design will be closely related to the removal and capping project element as specific components of the residual management layer and engineered isolation cap may serve as the substrate for habitat reconstruction. The basis of design will include a habitat reconstruction and enhancement component to replace and enhance the habitats of the Detroit River within the project footprint to those that currently exist in impacted area and in similar physical settings in nearby locations of the Detroit River.

7. Conceptual Design Components

This section identifies components to be addressed in the design. The subheadings essentially reflect major design tasks. Each section briefly describes the key activities to be completed as part of the design.

7.1 Remediation Area Boundaries

The remediation area boundaries are developed within the project footprint described in Section 3.2. The selected IM alternative comprises a dual approach consisting of sediment removal and capping. As a result, the various types of remediation boundaries for the project have been classified as a removal unit (RU) or cap unit (CU). The RUs and CUs define the precise locations of sediment removal and/or capping.

The design will include engineering drawings with control points establishing the RU and CU boundaries, and any required setbacks to avoid utilities, pipelines, or other structures. A coordinate system will be selected for these control points and the same coordinate system will be used throughout the design.

The specific areas defined will then be utilized in the development of dredge prisms and resuspension controls around work areas.

7.2 Mobilization and Site Preparation

Mobilization and Site preparation will include the establishment of staging areas, material handing areas, and dewatering and transport facilities. The specific areas the contractor will be required to use will be identified, and any preparation tasks, such as signage, navigational markers and lights, or other controls on access for safety and work area control purposes will be specified.

This task will also identify any expected monitoring activities, locations, and frequency for environmental monitoring that may be required during construction.

7.3 Resuspension Controls

Capping and removal activities are likely to cause sediment or other materials used for capping to re-suspend in the water column. Resuspension control process options, or physical methods to reduce the transport and migration of sediment, COCs, or other materials, may be necessary in various locations to meet applicable permits requirements and satisfy the basis of design.

The three main functions of resuspension control process options are: 1) isolate the remedial area (areas targeted for sediment removal and/or cap placement); 2) reduce the inflow to the remedial areas; and 3) capture the components associated with turbidity, thus controlling the downstream plume.

The overall approach for designing the resuspension control process options will include an evaluation of project requirements (i.e., permit) and the key elements and Site characteristics. The project footprints and prisms (areas and depths) for removal and cap placement to achieve the applicable criteria will also be utilized in the evaluation. The evaluation and selection of resuspension control systems will be conducted during the design phase.

7.4 Debris Management

Debris removal activities include the clearing of objects and obstructions from the riverbed and shoreline prior to removal and cap placement activities. Site investigation activities, visual observation, and hydrographic survey data indicate that concrete and construction debris are present in the areas adjacent to the Site scheduled for construction. Such debris may be removed either prior to or during removal activities, but must be removed prior to cap placement activities in areas where sediment removal was not previously conducted. It will likely be preferable to clear the larger debris at the sediment surface prior to removal and subsequently remove deeper debris that is encountered as part of the removal. The specific equipment utilized for debris removal operations will be evaluated during design but may include the use of a clamshell, excavator bucket, grapple, rake, or other appropriate equipment (depending on debris size, location, and characteristics).

Depending on the location of removal, debris may be transported either by truck or barge. The nature and extent of debris will determine final disposition of the material. The material may be disposed in a landfill or transported and disposed in the CDF. Further inquiries will be conducted to identify landfills for debris disposal and evaluations will be conducted to determine and estimate quantities of debris (see Section 6.3). These activities will be conducted during the design phase.

7.5 Removal Method and Limits

Sediment removal activities will begin after debris has been removed to the extent practicable. Sediment removal will be conducted via mechanical techniques as previously described in Section 4.2.5. It is currently anticipated that approximately 27,000 cy of material will require removal (Table 4-3). The preliminary locations for removal are depicted in Figure 4-1 and conceptually presented in Figure 4-2. Removal operations may be completed by water- and/or land-based operations, depending on the location of removal areas, depths of cutlines, and proximity to shoreline. The specific equipment to be utilized will be evaluated during design and will be based on an assessment of key project elements and Site characteristics. It is expected that the selected equipment will have features similar to those of commercially-available environmental clamshell buckets or equivalent.

There are multiple components to sediment removal methodology which must be evaluated and designed to ensure achievement of project objectives. Such components include, but are not limited to, the development of dredge prisms; the selection of the appropriate equipment; establishment of production rates; removal plan development identifying on an area-specific basis; work-day and work-hour limitations; identification of sensitive ecological habitats; presence of cultural or archaeological resources;, operational limitations due to seasonal factors such as ice, river operations, seasonal uses, or potential community impacts; and logistical obstacles such as bridges, dams, locks, or utilities, among others.

The confirmation of a successful sediment removal operation will be determined by verifying that the limits of the dredge prism (x, y, and z) have been achieved. Further discussion on verification is provided in Section 7.11.2. If the results indicate non-attainment of project objectives, contingency measures will be initiated.

The overall approach for designing the removal methodology will include an evaluation of project objectives, requirements and removal components in association with the key project elements, and Site characteristics. The evaluation and design of the removal component of the remedy will be conducted during the design phase.

7.6 Sediment and Water Processing

Following sediment removal from the river, the material will be transported upstream from the river-based operations to land-based disposal operations for final disposal of the material. Further detail on the transportation and disposal of the removed material is provided in Section 7.10. Based on the conceptual approach provided herein, the material is tentatively scheduled to be disposed of in the Pointe Mouillee CDF. Utilizing mechanical removal with engineering controls will reduce the total volume of water which may limit additional processing of material prior to disposal. Further evaluations will be conducted during the design phase to assess the physical characteristics of sediment scheduled for removal in conjunction with the disposal requirements at the CDF to determine if additional processing is required. This evaluation will also determine the need to implement water treatment operations.

7.7 Residuals Cover Layer Placement and Limits

The residual cover layer construction component of the remedy involves the installation of a thin layer of backfill material to be placed in RUs following removal activities. The preliminary locations for installation are depicted in Figure 4-1 and conceptually presented in Figure 4-2. Approximate quantities of required material are provided in Table 4-3.

Following removal activities, the RUs will be backfilled with a thin residuals cover to provide an immediate reduction of residual surface COC concentrations and to support and promote habitat reconstruction and enhancement. The residuals cover layer will consist of approximately 6 inches of a granular material which will be evaluated and determined during the design. Based on conceptual layout of RUs, approximately 850 cy of backfill material will be required. The selection of the material will incorporate various design elements and Site characteristics.

The overall backfill methodology and approach will include an evaluation of project objectives, requirements and individual backfill components in association with the key project elements and site characteristics. The design will incorporate all other construction activities that will affect this specific design component of the selected IM alternative and will be conducted during the design phase.

7.8 Cap Construction and Limits

The cap construction component of the selected IM alternative involves the construction of an engineered isolation cap. The preliminary locations for the construction of caps are depicted in Figure 4-1 and approximate quantities of required material are provided in Table 4-3.

The engineered isolation cap will be constructed to isolate impacted sediment, provide resistance to erosion, and provide the opportunity for habitat restoration. Engineered cap material will include granular soils or sediments for the isolation layer of the cap and, where necessary, will include larger stones (used in the armor layer) to resist hydrodynamic forces. In addition, depending on the particle sizes of the soil/sediment and armor layers, a filter layer composed of intermediate sized granular material or geosynthetic material may be required to stabilize the cap. Based on preliminary assessments, a conceptual engineered isolation cap has been developed as depicted in Figure 5-2. The cap consists of an approximately 1-foot sand isolation layer, a geotextile filter layer, and an approximately 1-foot erosion control component.

A capping plan will be developed which will contain all details and information required to efficiently and accurately install all components of the capping activities. The plan will provide details on equipment, a schedule of daily placement volumes in each capping area, account for factors such as navigable depth, required placement equipment, cycle times, downtime assumptions that account for equipment inefficiencies, difficulties during placement along the shoreline and near obstructions and material transport logistics.

The overall capping methodology and approach will include an evaluation of project objectives, requirements and individual capping components in association with the key project elements and site characteristics discussed above. The design will incorporate all other construction activities that will affect this specific design component of the selected IM alternative and will be conducted during the design phase.

7.9 Shoreline and Stability Control

The presence and location of shoreline structures will be considered paramount during design and implementation of the selected IM alternative. As previously described in Section 6, dredging operations in close proximity to the existing shoreline dock structure may lead to instability of the concrete dock, piers, and underdock sediment. As a result, removal activities proposed in Area C, along the southern portion of this concrete dock must be designed to avoid destabilization of the dock, piles and sediment located underneath the structure. The conceptual design will utilize a rigid sheet pile wall installed to native clay between the dock and the removal area, resulting in a protected length of dock. Sheet piles will be connected to the existing concrete wall to provide additional lateral support. The installation of the sheet pile system will be sequenced early in the construction activities so that it is in place and operational prior to initiating removal activities. Other portions of the existing dock structure located along the project footprint not scheduled for sediment removal will be left open to interact with channel hydraulics to allow natural deposition including migration of capping material during engineered isolation cap construction.

The specific components and design of the sheet pile wall will be evaluated during design and will incorporate results from the pre-design investigations.

7.10 Dredged Material Transportation and Disposal

The transportation and disposal of materials removed during the selected IM alternative involves the movement of sediment removed from the point of origin to the point when the material barges are docked at the offloading facility to the final placement in the CDF. As previously discussed, mechanical removal will be utilized for sediment removal operations. As material is excavated from the channel bottom, it will be placed into a barge/scow. After loading, the barges will be maneuvered by a tender tug to outside the limits of the resuspension control system (depending on location) and upriver to the offloading facility for disposal. Once barges are docked at the offloading facility, the disposal component of the IM will commence. Depending on the volume of material scheduled for removal, offloading facility improvements may be required and will be evaluated during later design stages. Sediments located in the barges will be removed via the use of excavators or cranes, loaded directly into dump trucks and transported to the CDF. After the full barges have been unloaded they will be transported back to the dredge areas. The material will be distributed evenly throughout the CDF and at a consistent depth to achieve a uniform surface in preparation for CDF capping. Cap material will be consistent with USACE guidance and that which has been previously utilized at the CDF. In addition, the construction of a sub-cell to the existing CDF may be required to accommodate the volume of material scheduled for dredging. This determination will be made during the design phase.

The overall approach for the transport and disposal of removed material will include an evaluation of project objectives, requirements, and individual transport and disposal components in association with the key project elements and site characteristics. The design will incorporate all other construction activities that will affect this specific design component and will be conducted during the design phase.

7.11 Environmental Monitoring Plan

7.11.1 Resuspension Control Plan

A Resuspension Monitoring and Control Plan will be implemented in accordance with permit requirements to control increases in turbidity levels attributable to IM activities in the channel. To reduce the migration of water column disturbances inevitable during construction activities of this nature, resuspension controls will be installed prior to the commencement of construction activities. Inspections of the resuspension control systems will be conducted on a daily basis prior to the beginning of removal activities. Additional inspections will also be conducted, as appropriate, in response to visible sediment plumes migrating from the work area or measured turbidity levels above the action level (described below).

To ensure that the implemented resuspension controls prove effective for turbidity, data will be collected daily using turbidity monitoring devices from locations upstream and downstream of a given work area. Readings will be collected from approximately mid-depth at all locations. Downstream data will be compared to concurrent upstream data to identify increases in turbidity. The data can be collected mechanically by Site personnel via a boat or through the use of installed monitoring equipment using telemetry. The monitoring units will be calibrated, operated, and maintained according to the manufacturer's instructions.

In the event turbidity increases reach unacceptable levels, a range of mitigation measures will be implemented based on the magnitude of the turbidity increases. Such mitigation measures may include modifications to dredge and cap operations (e.g., fall height, cycle time, bucket handling procedures, use of a rinse tank, placement procedures, etc.) or modifications of the resuspension control system such as the addition of a secondary system.

7.11.2 Construction Verification/Confirmation

After construction is believed to be complete within a targeted area, monitoring will be performed to confirm that the design specifications have been achieved. Confirmation of the removal of sediments to the cut lines established during final design will be based on survey data collected from the targeted remediation area. Removal will be considered complete when removal is performed to the cut line based on the maximum depth of penetration of the bucket as measured by the Real Time Kinematic Global Positioning System, and the bottom elevation is shown to be within the specified dredge tolerances. In addition, bathymetric surveys will be conducted at the conclusion of cap placement activities to verify placement elevations were achieved. Appropriate quality control and traditional survey techniques will be utilized to certify final CDF cap (individual component/layers) construction.

7.11.3 Post Construction Site Control Plan

Site controls will be implemented following the completion of removal and cap placement activities. Such controls and their requirements would include:

- Shoreline stability monitoring to identify potential impacts as a result of IM implementation. Monitoring would include visual observations of the bank for signs of detrimental erosion or failure and of the structures themselves for stability concerns. If any of these are observed during the monitoring period, the need for repair activities will be discussed with the oversight agencies and implemented as appropriate.

- Cap monitoring to document the existing cap conditions and progress toward the post-construction project objectives. Monitoring would include visual observations of the cap layers for areas of erosion or disruption; photo documentation of the existing cap conditions; and documentation of any bubbles, sheens, or other inconsistencies identified during visual observations. Maintenance activities may be necessary to address observed deficiencies or damage.

Actual Site control selection and implementation will be further evaluated during design phases of the selected IM alternative and following approval from regulating agencies.

Monitoring reports will be developed to document the observations made during inspections (i.e., the stability of bank structures and cap integrity) at appropriate intervals during the monitoring period. The reports will summarize the progress toward project objectives, describe any maintenance activities necessary, and include photo-documentation of bank conditions and vegetation development from established vantage points.

7.12 Habitat Reconstruction and Enhancement

The habitat reconstruction and enhancement program is intended to replace and enhance the habitats of the Detroit River to those that currently exist in the project footprint and in similar physical settings in nearby locations. As previously described, the habitat reconstruction and enhancement will be closely related to the dredging and capping project element as specific components of the thin residual management layer and engineered isolation cap may serve as the substrate for habitat reconstruction.

Habitat reconstruction and enhancement will be performed following removal activities as an element of the thin residual management layer component and engineered isolation cap component of the selected IM alternative. The selected material for the thin residual management layer will focus on providing suitable habitat for biota. In those areas where engineered isolation caps are proposed, i.e. to the north and south of the proposed USACE dock, the armoring material will be designed to be both stable and long-lasting; however, suitable material for fish spawning and benthic macroinvertebrate recolonization will also be considered to supplement this proposed armor material. In addition, both components may include materials such as large woody debris and/or boulders that can be added to the surface of the cap material to provide structure in unconsolidated bottom habitat. Furthermore, the reconstruction of the habitat will rely on natural riverine processes (i.e., deposition) to aid in the replacement and enhancement of the system.

Habitat delineation and assessment activities will be conducted as a component of the pre-design investigations as specified in Section 5. These activities will collect quantitative data for the specific structural parameters to be used as design criteria for the habitat reconstruction program.

The implementation and distribution of habitat reconstruction treatments, and criteria for selecting location-specific treatment alternatives within remediated areas will be evaluated and specified during the design phase.

7.13 Demobilization and Restoration

Following completion of construction activities, Site demobilization and restoration will be conducted. This will consist of Site restoration activities at the Site and the CDF; removal of all temporary work-related facilities, equipment, and materials; and final inspection of all work and restored areas. Any disturbed areas affected as a result of construction activities will be replaced to pre-construction conditions. Restoration at the Site will consist of replanting any damaged trees or other vegetation, removal of the temporary parking areas and staging areas, removal of the field office trailers and utilities and temporary security fence, and seeding of all disturbed areas. Any refuse or waste construction materials will be removed and properly disposed. Final inspection will be conducted following the aforementioned activities and the final acceptance certificate will be issued.

8. Required Permits

Applicable and necessary permits will be attained prior to initiating construction of the selected IM alternative. A MDNRE/USACE joint permit application will be required as well as other applicable state and local permits. Tables 8-1 and 8-2 summarize the applicable permits. As part of the design process, permit applications will be prepared and submitted.

Not all of the above-listed permits are anticipated to be applicable to the Site; however, additional information will be required to make that determination. Permit requirements will be a key component of the design phase of the project. Additional permits, such as storm water management or water treatment/discharge permits may be required if removed sediments and material cannot be transported to the Pointe Mouliee CDF for disposal.

Table 8-1 – MDNRE/USACE Joint Permit Application

Regulatory Agency	Regulation	Description
MDNRE	Part 301, Inland Lakes and Streams, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Regulates activities including dredging, filling, constructing or placing a structure on bottom lands, constructing or operating a marina, interfering with natural flow of water or connecting a ditch or canal to an inland lake or stream.
MDNRE	Part 303, Wetlands Protection, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Required for activities proposed in regulated wetland areas.
MDNRE	Part 325, Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Regulates construction activities along Great Lake shoreline and bottom lands, including coastal marshes.
MDNRE	Part 31, Water Resources Protection (Floodplain Permit), Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Required for activities within the 100-year floodplain and floodway of a river, stream, drain, or inland lake.
MDNRE	Part 353, Sand Dunes Protection and Management, Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Required for proposed construction activities in designated critical dune areas (CDA's)
MDNRE	Part 323, Shorelands Protection and Management, Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Required for any activities within a designated environmental area or high risk erosion area.
MDNRE	Part 315, Dam Safety, Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Regulates activities on dams, and dikes with a height of 6 feet or more that have impoundments with a surface area of 5 acres or more at the design flood elevation.
USACE	Section 10, Rivers and Harbors Act of 1899 (33. U.S.C. 403)	Required for activities including obstruction or alteration of navigable waters in the U.S. Navigable waters associated with Michigan include the Great Lakes, their tributaries, and associated wetlands.
USACE	Section 404, Clean Water Act of 1977 (33 U.S.C. 1344)	Required for the discharge of dredged or fill material into all waters of the U.S. including adjacent wetlands. The discharge of any fill materials must comply with state water quality standards consistent with the Clean Water Act.
USACE	Disposal	Use of Pointe Mouillee CDF

Table 8-2 – Other Applicable Permits

Issuing Agency/Permit	Regulation	Description
MDNRE Soil Erosion and Sedimentation Control	Part 91, Soil Erosion and Sedimentation Control, Great Lakes Submerged Lands, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Applicable to dredging and construction activities. Required for any earth change that disturbs one or more acres, or is within 500 feet of a lake or stream.
MDNRE Air Quality	Part 55, Air Pollution Control, Natural Resources and Environmental Protection Act, Public Act 451 of 1994, as amended	Required if installation, construction, reconstruction, relocation, or modification of any process or process equipment may emit an air contaminant.
Wayne County Construction Permit	State of Michigan's County Road Law	Required if work is performed in the public road right-of-way, County owned property or on a County drain easement.
City of Wyandotte Local Ordinances	Numerous	May include general construction permits, noise permits and work hour regulations.

9. Key Submittals and Schedule

9.1 Key Submittals

9.1.1 Planning and Pre-Construction Submittals

The following key submittals are anticipated during the design and pre-construction planning process:

- **Sampling plans** – Data collection for design will be described in letter sampling plans for agency review.

- **60 percent design** – Review and approval of the IMDWP will initiate production of a design/work plan for implementation of the selected IM. An intermediate step for completion of the design/work plan will be the completion of a 60% design with associated contract drawings and specifications. This design will include the results of available data collected for design purposes.

- **Pre-Final design (i.e. 95% design), including design report, contract drawings, and specifications** – The pre-final design will essentially be a final design (see below) for comment by USEPA.

- **Final design (i.e. 100% design), including design report, contract drawings, and specifications –** The report will include finalized design based on data collected to satisfy the data needs and finalized contract drawings and specifications will be prepared.

- **Quality Assurance Project Plan (QAPP) –** A Site-specific QAPP has been prepared and submitted to USEPA (Environmental Science and Engineering, Inc. 1996 with addenda submitted by ARCADIS 2008b and 2009c). It is anticipated that the QAPP will be amended as necessary to describe any sampling efforts conducted during construction that are outside the scope of the current QAPP.

- **Health and Safety Plan (HASP)** – A HASP will be prepared by the contractor(s) responsible for construction to provide for the health and safety of workers, visitors, and the public during construction.

The submittals include pre-and post-construction reports and the design/work plan for construction of the selected IM alternative.

9.1.2 Post-Construction Submittals

Following completion of the project, the completion of the selected IM alternative will be documented, and a monitoring and inspection period may be needed. The following post-construction submittals are anticipated:

- **Construction Completion Report** – this report will be prepared following the completion of construction and a successful final inspection by USEPA. This report will document that the selected IM alternative has been constructed in accordance with the design or note any deviation from the design.

- **Post-Construction Monitoring Report** – this document will report results of inspections and monitoring of remediation areas and habitat restoration/enhancement areas post-construction.

9.2 Design Schedule

9.2.1 Major Milestones

Major milestones for this project include the completion and approval of necessary plans and obtaining necessary permits. The key milestones are anticipated to be the following, in this sequence:

- IMDWP approval
- 60% Design submittal
- 60% Design review and comments from USEPA
- Submittal of permit applications
- Submittal of Pre-Final (95%) Design, Contract Drawings, and Specifications
- 95% Design review and comments from USEPA
- Submittal of Final Design, Contract Drawings, and Specifications
- Approval of Final Design, Contract Drawings, and Specifications from USEPA

- QAPP and HASP submittal

The approval of the 60% design will initiate the process to attain required permits.

An estimated major milestones schedule is presented in Table 9-1.

Table 9-1 – Major Milestones and Estimated Schedule

Milestone	Estimated Timeframe
Approval of IMDWP	-
Submittal of 60% Design	Within 180 days of IDMWP approval. Not sooner than 90 days following receipt of data from additional sampling.
Approval of 60% Design	-
Initiation of Permitting Process	Upon approval of 60% Design
Submittal of Pre-Final (95%) Design	Within 270 days of IDMWP approval
Receipt of USEPA Comments	-
Submittal of Final Design for Approval	Within 45 days of receipt of USEPA comments
Approval of Final Design	-
Initiation of Construction Activities	To be determined
Implementation of Construction	To be determined – *Subject to timing of design and details of selected approach.*

9.2.2 Design and Planning Meetings

The following meetings with USEPA are anticipated:

- Periodic status update calls with USEPA and MDNRE, as needed
- A meeting to review the 60% design
- A meeting to review the draft final design and implementation schedule
- Potentially other meetings on an as-needed basis to discuss technical issues

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ARCADIS

Tables

BASF Corporation - North Works
Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table 4-3 - Alternative Components and Quantities

Remedial Areas Identification	Subareas (ac)	Interim Measure Alternative 1				Interim Measure Alternative 2				Interim Measure Alternative 3				Interim Measure Alternative 4				Interim Measure Alternative 5			
		No Action				Monitored Natural Recovery				Mechanical Removal with Residual Management				Partial Removal and Cap Placement				Targeted Removal with Cap Placement			
		Removal Volume (cy)	Cap Volume (cy)			Removal Volume (cy)	Cap Volume (cy)			Removal Volume (cy)	Cap Volume (cy)			Removal Volume (cy)	Cap Volume (cy)			Removal Volume (cy)	Cap Volume		
			RCL (cy)	Isolation			RCL (cy)	Isolation			RCL (cy)	Isolation			RCL (cy)	Isolation			RCL (cy)	Isolation	
				Sand (cy)	Armor Layer (tons)			Sand (cy)	Armor Layer (tons)			Sand (cy)	Armor Layer (tons)			Sand (cy)	Armor Layer (tons)			Sand (cy)	Armor Layer (tons)
A	1.2	---	---	---	---	---	---	---	---	9,100	1,000	---	---	3,900	---	1,900	2,900	---	---	1,900	2,900
B	1.3	---	---	---	---	---	---	---	---	7,400	---	---	---	7,400	---	---	---	7,400	---	---	---
C	1.0	---	---	---	---	---	---	---	---	8,500	800	---	---	8,500	800	---	---	8,500	800	---	---
D	0.6	---	---	---	---	---	---	---	---	4,700	---	---	---	4,700	---	---	---	4,700	---	---	---
E	3.2	---	---	---	---	---	---	---	---	4,500(1)	400	---	---	10,500	---	5,200	7,800	---	---	5,200	7,800
F	1.1	---	---	---	---	---	---	---	---	6,400	---	---	---	6,400	---	---	---	6,400	---	---	---
Total	8.4	---	---	---	---	---	---	---	---	40,600	2,200	---	---	41,400	800	7,100	10,700	27,000	800	7,100	10,700

Notes:

(1) Only two sub-sections of Area E, E-1 and E-2 (as presented on Figure 5-1), will be addressed by the interim measures implemented for Aternative 3. These areas combined are approximately 0.5 acre in size.

(2) ac - Acres.

(3) cy - Cubic yards.

(4) RCL - Residuals cover layer.

(5) Isolation - Engineered isolation cap.

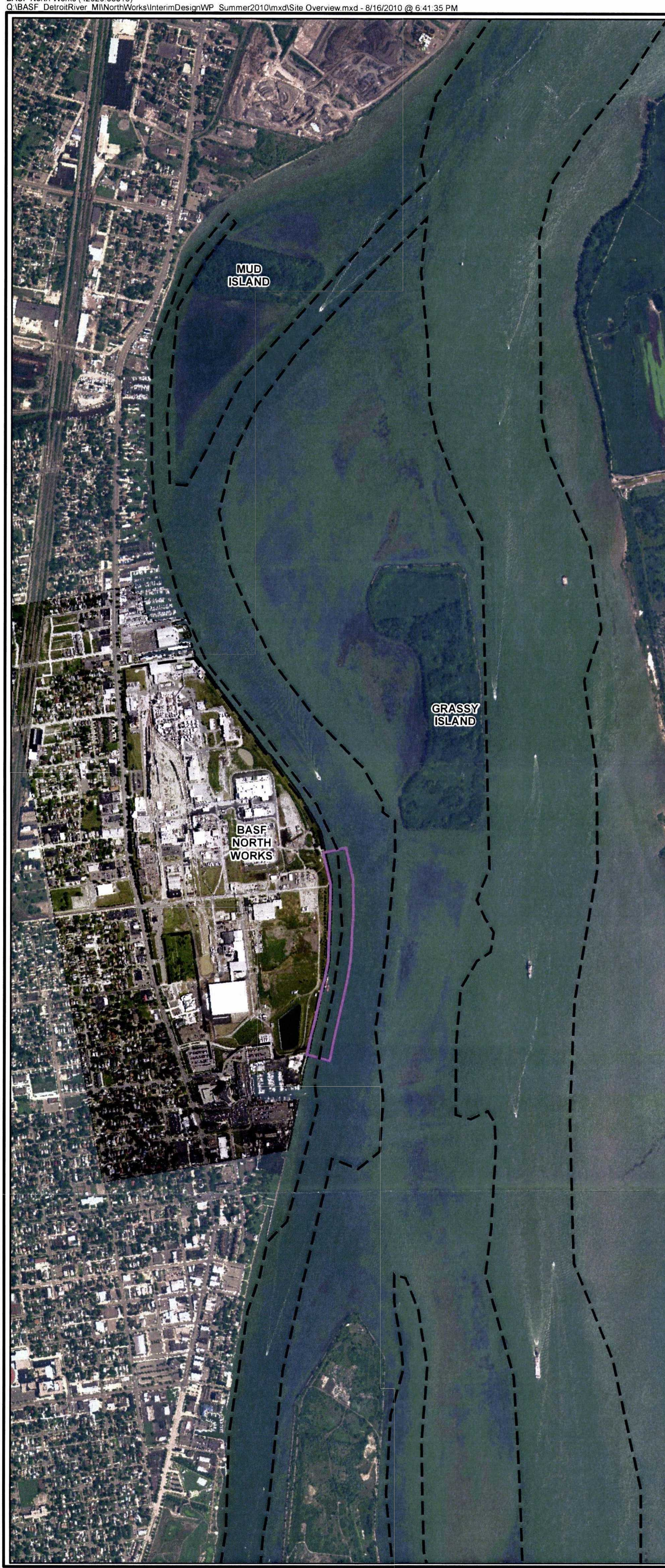
BASF Corporation - North Works
Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table 4-4 - Comparative Analysis of Interim Measure Alternatives

Evaluation Criteria	Interim Measure Alternative 1 No Action	Interim Measure Alternative 2 Monitored Natural Recovery	Interim Measure Alternative 3 Mechanical Removal with Residual Management	Interim Measure Alternative 4 Partial Removal and Cap Placement	Interim Measure Alternative 5 Targeted Removal with Cap Placement
Protect Human Health and the Environment	May not be protective of human or ecological receptors as no control of exposure to impacted sediments is provided and existing potential risks are not reduced (stated on premise that current exposure levels are unacceptable).	No immediate reduction to exposure is provided and the rate of Site-specific natural recovery processes remain unknown. However, long term monitoring would be implemented to evaluate the contribution of natural processes to the reduction of Site-related COCs and ensure that long term risks are appropriately managed and controlled.	Provides adequate protection to human and ecological receptors by removing impacted sediments. Overall protection will vary depending on accuracy of removal operations to limit residual contamination following removal and effectiveness of engineering/operational controls implemented during construction to reduce resuspension of impacted sediments. Placement of a residuals cover layer provides immediate reduction in residual COC concentrations within Area C and portions of Area E, decreasing bioavailability to ecological receptors; however, the removal within Area A and portions of Area E (13,600 cy) may increase the potential for exposure to COCs and further impact the water quality and disrupt the aquatic habitat.	Provides protection to human and ecological receptors by removing impacted sediments and by mitigating future migration of COCs via placement of an isolation cap. Overall protection will vary depending on effectiveness of engineering/operational controls implemented during construction to reduce resuspension of impacted sediments and accuracy of removal operations to limit residual contamination. Placement of a residuals cover layer provides immediate reduction in residual COC concentrations within Area C, decreasing bioavailability to ecological receptors; however, the partial removal within Areas A and E (14,400 cy) to accommodate cap placement may increase the potential for exposure to COCs, further impact the water quality and disrupt the	Provides protection to human and ecological receptors by removing impacted sediments and by mitigating future migration of COCs via placement of an isolation cap. Overall protection will vary depending on effectiveness of engineering/operational controls implemented during construction to reduce resuspension of impacted sediments and accuracy of removal operations to limit residual contamination. Placement of a residuals cover layer provides immediate reduction in residual COC concentrations, decreasing bioavailability to ecological receptors.
Attainment of Cleanup Goals	The applicable cleanup standards may not be met.	May reduce concentrations of Site-related COCs to achieve targeted cleanup values.	Although resuspended and residual sediments resulting from removal operations may prolong the attainment of cleanup standards in the short term, cleanup standards and project objectives are likely to be attained within areas addressed by the alternative.	Cleanup standards and project objectives are likely to be achieved through reduction of the contaminant mass via sediment removal and physical isolation of impacted sediments via cap placement. Although, in the short term, resuspended and residual sediments may prolong the attainment of cleanup standards.	Cleanup standards and project objectives are likely to be achieved through reduction of the contaminant mass via sediment removal and physical isolation of impacted sediments and residuals via cap placement. Although, in the short term, resuspended and residual sediments may prolong the attainment of cleanup standards.
Source Control	Upstream sources of constituent release will not be controlled.	Upstream sources of constituent release will not be controlled.	Upstream sources of constituent release will not be controlled. Although, recontamination following remedy implementation is likely to be consistent with background levels.	Upstream sources of constituent release will not be controlled. Although, recontamination following remedy implementation is likely to be consistent with background levels.	Upstream sources of constituent release will not be controlled. Although, recontamination following remedy implementation is likely to be consistent with background levels.
Compliance with Applicable Waste Management Standards	Waste management is not applicable.	Waste management standards would be met for general refuse and removed sediment associated with sampling and monitoring activities.	Waste management standards would be met for general construction debris and refuse, debris removed during Site development and from the sediment bed, sediments removed from the channel bottom, and any wastewater resulting from the interim measure. Disposal of sediments is anticipated to occur at the Pointe Mouillee CDF.	Waste management standards would be met for general construction debris and refuse, debris removed during Site development and from the sediment bed, sediments removed from the channel bottom, and any wastewater resulting from the interim measure. Disposal of sediments is anticipated to occur at the Pointe Mouillee CDF.	Waste management standards would be met for general construction debris and refuse, debris removed during Site development and from the sediment bed, sediments removed from the channel bottom, and any wastewater resulting from the interim measure. Disposal of sediments is anticipated to occur at the Pointe Mouillee CDF.
Long Term Reliability and Effectiveness	All potential current and future risks would remain the same except as subject to natural changes over time. Does not provide any controls for reduction of exposure, long term management or monitoring measures.	There is evidence of MNR processes contributing to the reduction in surface sediment exposure levels, however, long term effectiveness cannot reliably be assessed based on the current understanding of the Site. Timeframe for achievement of project objectives is therefore unknown but is anticipated to occur over an extended period of time with increasing degree of watershed source controls. May reduce COC concentrations if Site conditions are conducive to MNR processes compatible with Site-related COCs.	Long term effectiveness and residual risk after removal activities are dependent on limitations associated with the dredging technology and the volume of residual contamination following removal. Sediment removal as a component of this alternative provides long term reduction to contaminant concentrations, but placement of a residuals cover layer will only provide short term reduction in exposed residual concentrations. Long term effectiveness of residuals management would rely upon natural processes (i.e., deposition) to mitigate migration of the remaining residual concentrations.	Long term effectiveness and residual risk after removal activities are dependent on limitations associated with the dredging technology and residual COC concentrations. Sediment removal and sediment isolation as components of this alternative provide long term reduction and isolation to contaminant concentrations. Placement of a residuals cover layer only provides short term reduction in exposed residual concentrations. Long term effectiveness of residuals management would rely upon natural processes (i.e., deposition) to mitigate migration of the remaining concentrations within Area C. Long term monitoring will be conducted to ensure project objectives are achieved. Placement of an engineered isolation cap is not anticipated to have any long term affect on future navigation requirements as cap placement is in select areas.	Long term effectiveness and residual risk after removal activities are dependent on limitations associated with the dredging technology and residual COC concentrations. Sediment removal and sediment isolation as components of this alternative provide long term reduction and isolation to contaminant concentrations. Placement of a residuals cover layer only provides short term reduction in exposed residual concentrations. Long term effectiveness of residuals management would rely upon natural processes (i.e., deposition) to mitigate migration of the remaining concentrations within Area C. Long term monitoring will be conducted to ensure project objectives are achieved. Placement of an engineered isolation cap is not anticipated to have any long term affects on future navigation requirements or flood storage capacity as cap placement is only in select areas.

BASF Corporation - North Works
Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table 4-4 - Comparative Analysis of Interim Measure Alternatives

Evaluation Criteria	Interim Measure Alternative 1 No Action	Interim Measure Alternative 2 Monitored Natural Recovery	Interim Measure Alternative 3 Mechanical Removal with Residual Management	Interim Measure Alternative 4 Partial Removal and Cap Placement	Interim Measure Alternative 5 Targeted Removal with Cap Placement
Reduction in the Toxicity, Mobility, or Volume of Wastes	Does not reduce the toxicity, mobility, or volume of impacted sediments.	There is evidence of MNR contributing to the reduction of Site-related COC toxicity. Mobility of surface sediment exposure levels is not addressed by this alternative.	Effectively reduces toxicity and volume of Site-related COCs by removing a significant volume of impacted sediments, including the removal of 13,600 cy scheduled within Area A (1.2 acres) and portions of Area E (0.5 acres). Placement of a residuals cover layer within Areas A, C and portions of Area E will reduce the mobility of residuals remaining subsequent to removal activities. In addition, potential for the mobility of COCs by resuspension will be minimized via implementation of engineering/operational controls.	Effectively reduces toxicity and volume of Site-related COCs by removing a significant volume of impacted sediment, including the removal of 14,400 cy scheduled within Areas A and E (4.5 acres) to accommodate cap placement. Placement of a residuals cover layer within Area C will reduce the mobility of residuals remaining subsequent to removal activities. In addition, potential for mobility of COCs by resuspension will be minimized via implementation of engineering/operational controls. Placement of an engineered isolation cap will control contaminant flux into the overlying water column from impacted sediments that are located below the depth of removal within Areas A and E.	Effectively reduces toxicity and volume of Site-related COCs by removing a significant volume of impacted sediments. Placement of a residuals cover layer within Area C will reduce the mobility of residuals remaining subsequent to removal activities. In addition, potential for mobility of COCs by resuspension of sediments will be minimized via implementation of engineering/operational controls. Placement of an isolation cap will control contaminant flux into the overlying water column from impacted sediments within Areas A and E.
Short Term Effectiveness	Will not mitigate any existing or potential future risks in the short term, but does not pose any additional risk to the community, construction workers, or the environment.	Will not immediately mitigate risks associated with human and ecological exposure to impacted sediments, however implementation does not pose any additional risk to the community, workers, or the environment.	Immediate reduction in bioavailability is provided by sediment removal. Short term impacts resulting from removal operations, such as resuspension and residual sediments, will be reduced via implementation of engineering/operational controls and placement of a residuals cover layer. A large volume of sediment scheduled for removal may prolong the duration of short term impacts, such as temporary reduction in water quality and increased disturbance to the aquatic habitat. Potential for increased short term risks to the community, construction workers and the environment. Minor Site disturbances will be ensued.	Immediate reduction in bioavailability and isolation to impacted sediments is provided by sediment removal and placement of an engineered isolation cap. Short term impacts resulting from removal operations, such as resuspension and residual sediments, will be reduced via implementation of engineering/operational controls and placement of a residuals cover layer. A large volume of sediment scheduled for removal may prolong the duration of short term impacts, such as temporary reduction in water quality and increased disturbance to the aquatic habitat. Potential for increased short term risks to the community, construction workers and the environment. Minor Site disturbances will be ensued.	Immediate reduction in bioavailability and isolation to impacted sediments is provided by sediment removal and placement of an engineered isolation cap. Short term impacts resulting from removal operations, such as resuspension and residual sediments, will be reduced via implementation of engineering/operational controls and placement of a residuals cover layer. May temporarily decrease water quality and disturb aquatic habitat. Potential for increased short term risks to the community, construction workers and the environment. Minor Site disturbances will be ensued.
Implementability	N/A	There are no implementability concerns posed by this alternative.	Readily implementable and previously demonstrated technology. Water depths are sufficient for water-based operations, but equipment is adaptable to land-based operations within remedial areas adjacent to the shoreline, as necessary. Removed sediment can be transported to the Pointe Mouillee CDF via barge transport. Site constraints, such as debris within remedial areas and existing bank structures, may pose implementability concerns. Minimal upland staging and support areas are needed. Removal of a larger volume of sediment will result in longer project durations and require additional logistical coordination (i.e., equipment availability for project duration) as well as corresponding increased costs. Increased project duration may require multiple construction seasons and multiple mobilization/demobilization for remedy completion.	Readily implementable and previously demonstrated technology. Water depths are sufficient for water-based operations, but equipment is adaptable to land-based operations within remedial areas adjacent to the shoreline, as necessary. Removed sediment can be transported to the Pointe Mouillee CDF via barge transport. Site constraints, such as debris within remedial areas and existing bank structures, may pose implementability concerns. Minimal upland staging and support areas are required. Removal of a larger volume of sediment in conjunction with cap placement will result in longer project durations and require additional logistical coordination (i.e., equipment availability for project duration) as well as corresponding increased costs. Increased project duration may require multiple construction seasons and multiple mobilization/demobilization for remedy completion.	Readily implementable and previously demonstrated technology. Water depths are sufficient for water-based operations, but equipment is adaptable to land-based operations within remedial areas adjacent to the shoreline, as necessary. Removed sediment can be transported to the Pointe Mouillee CDF via barge transport. Site constraints, such as debris within remedial areas and existing bank structures, may pose implementability concerns. Minimal upland staging and support areas are required Potential for implementation to occur within one construction season.
Cost (to be revised following completion of cost estimates)	There are no costs associated with this alternative.	TBD	TBD	TBD	TBD

Figures



LEGEND:
NAVIGATION CHANNEL (APPROXIMATE)
BASF - NORTH WORKS FACILITY
APPROXIMATE STUDY AREA

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. AERIAL IMAGERY PROVIDED BY THE MICHIGAN CENTER FOR GEOGRAPHIC INFORMATION.

0 1,300 2,600 Feet
GRAPHIC SCALE

DRAFT FOR FEDERAL AND STATE REVIEW

BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI

INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS

SITE OVERVIEW

ARCADIS

FIGURE 1-1

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\Sediment Thickness.mxd - 8/16/2010 @ 6:40:01 PM

LEGEND:

- ● 2008 AND 2009 SEDIMENT CORE LOCATIONS

SHORELINE CLASSIFICATION:

- CONCRETE BULKHEAD
- METAL SHEET PILING
- RIP-RAP
- 2009 WATER DEPTH CONTOUR (1 FT)

SEDIMENT THICKNESS ABOVE CLAY (FT):

- 0
- 0 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- > 7
- 2-FOOT SEDIMENT THICKNESS CONTOUR

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI

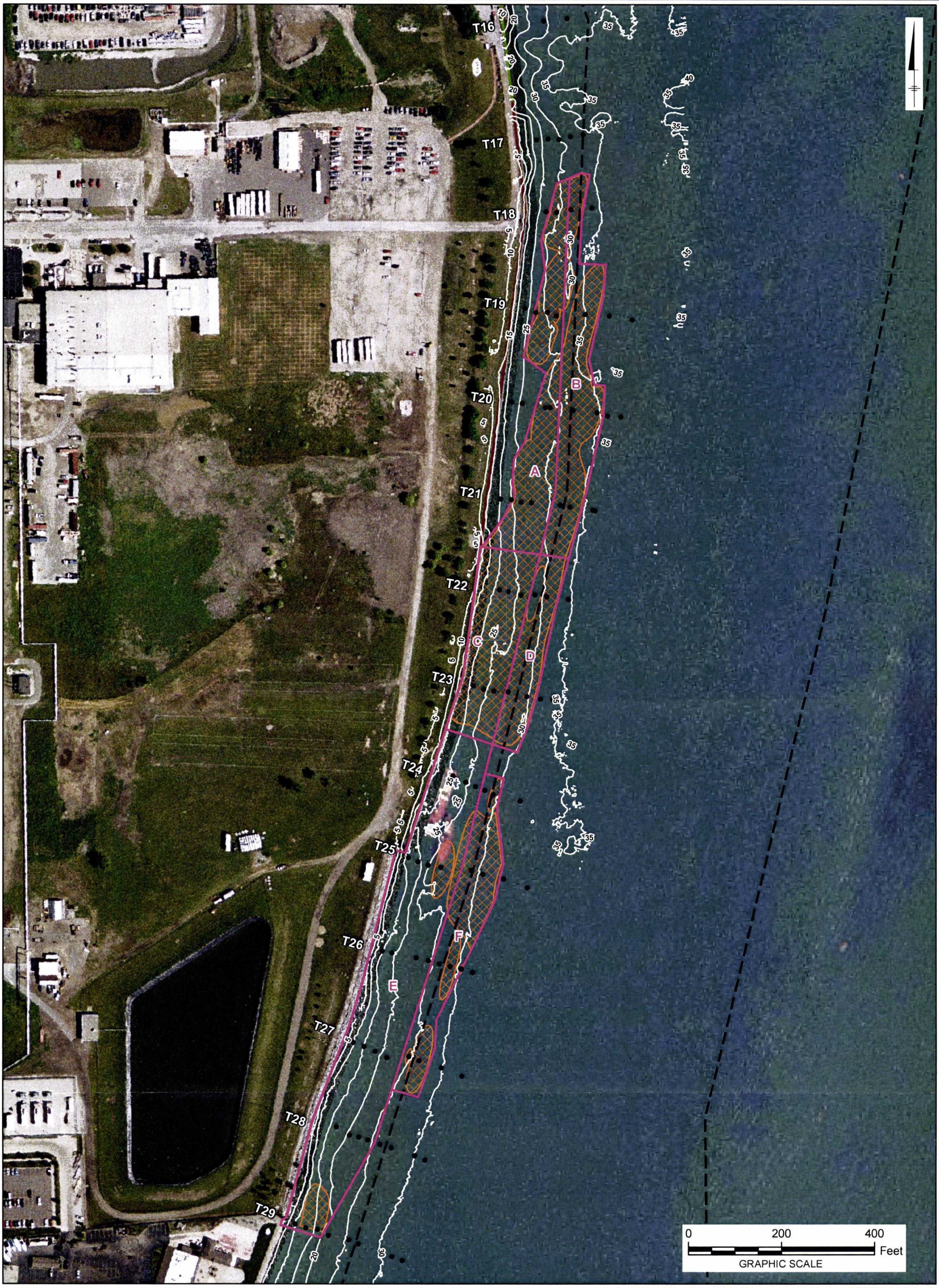
INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS

PHYSICAL CHARACTERISTICS OF THE SHORELINE AND SEDIMENTS

ARCADIS

FIGURE
1-2

CITY: SF DIV/GROUP: IM DB: KERNST LD: PIC: PM: TM: TR:
Project (Project #) B0042929.0019.00020
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\Removal Area Footprint.mxd - 8/18/2010 @ 3:54:11 PM



LEGEND:

- SEDIMENT CORE LOCATION
- NAVIGATION CHANNEL (APPROXIMATE)

SHORELINE CLASSIFICATION:

- CONCRETE BULKHEAD
- METAL SHEET PILING
- RIP-RAP

- FOOTPRINT AREA (GIS OUTPUT)
- SUBAREA (CONSTRUCTIBLE)
- 2009 WATER DEPTH CONTOURS (5 FT)

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI

INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS

PROJECT FOOTPRINT

ARCADIS

FIGURE **3-1**

CITY: SF DIV/GROUP: IM DB: KERNST LD: PIC: PM: TM: TR:
Project (Project #) B0042929.0019.00020
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\Interim Measure.mxd - 8/18/2010 @ 4:02:21 PM

LEGEND:

- SEDIMENT CORE LOCATION
- 2009 WATER DEPTH CONTOURS (5 FT)
- NAVIGATION CHANNEL (APPROXIMATE)

SHORELINE CLASSIFICATION:

- CONCRETE BULKHEAD
- METAL SHEET PILING
- RIP-RAP

SUBAREA (CONSTRUCTIBLE)

- CAP AREA
- SEDIMENT REMOVAL
- SEDIMENT REMOVAL WITH RESIDUALS COVER LAYER

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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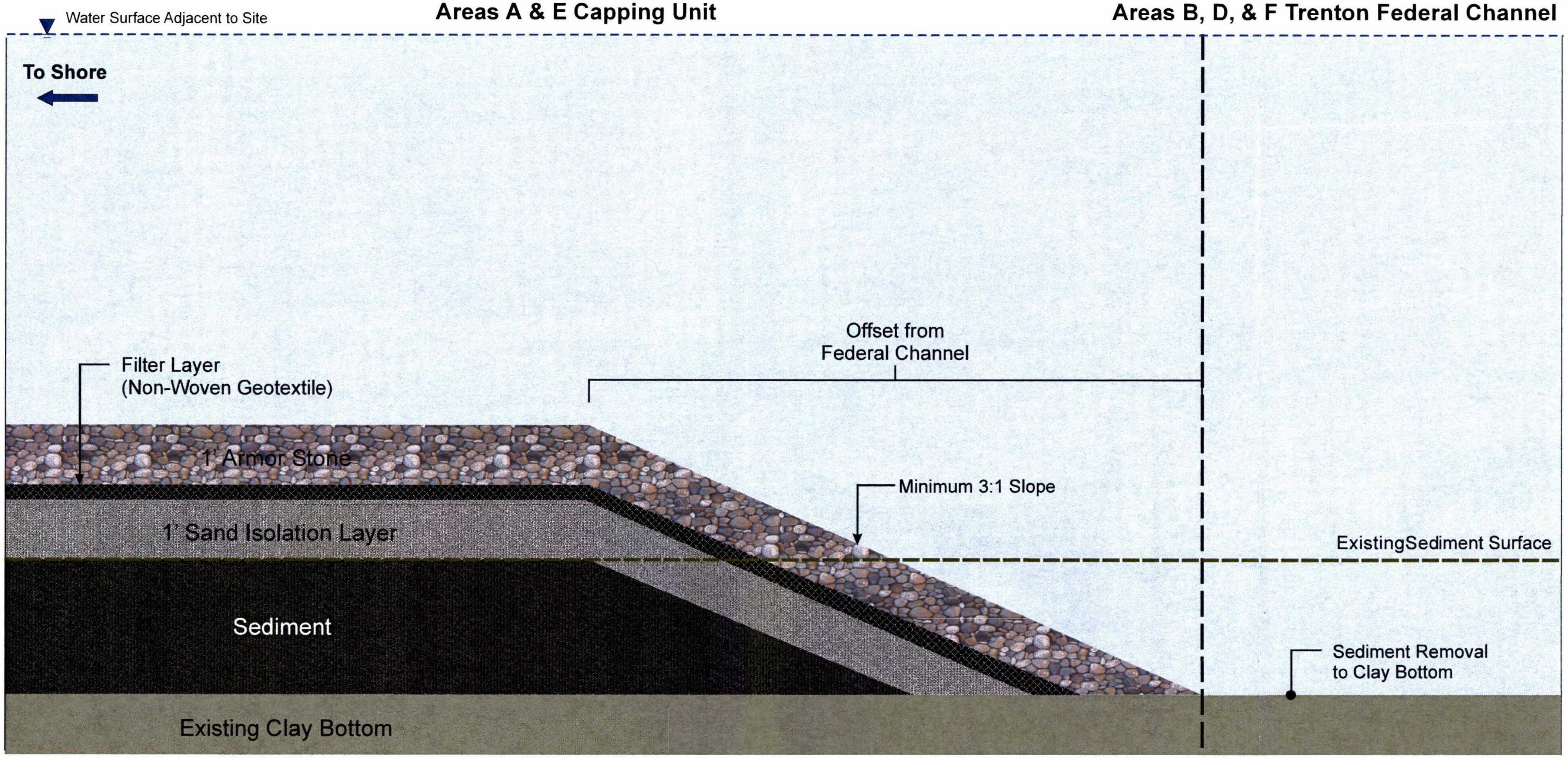
BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI

INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS

PREFERRED INTERIM MEASURE

ARCADIS

FIGURE
4-1



NOT TO SCALE

Note:

1. The conceptual remedial components presented heron depicts interim measure Alternative 5 to be implemented within Areas A, B, D, E & F. The engineered isolation cap to be constructed within Areas A & E will consist of, frombottom to top, a 1 foot sand isolation layer, a filter layer consisting of a non-woven geotextile, and a 1 foot armor layer consisting of stone. No cap materials will be placed within the federal channel, Areas B, D & F.

2. Removal depth and cap thickness shown are not to scale and should be considered conceptual.

3. Removal depth and specific cap function, components, thicknesses, and material are dependent on site characteristics and require extensive site investigation, modeling, and design.

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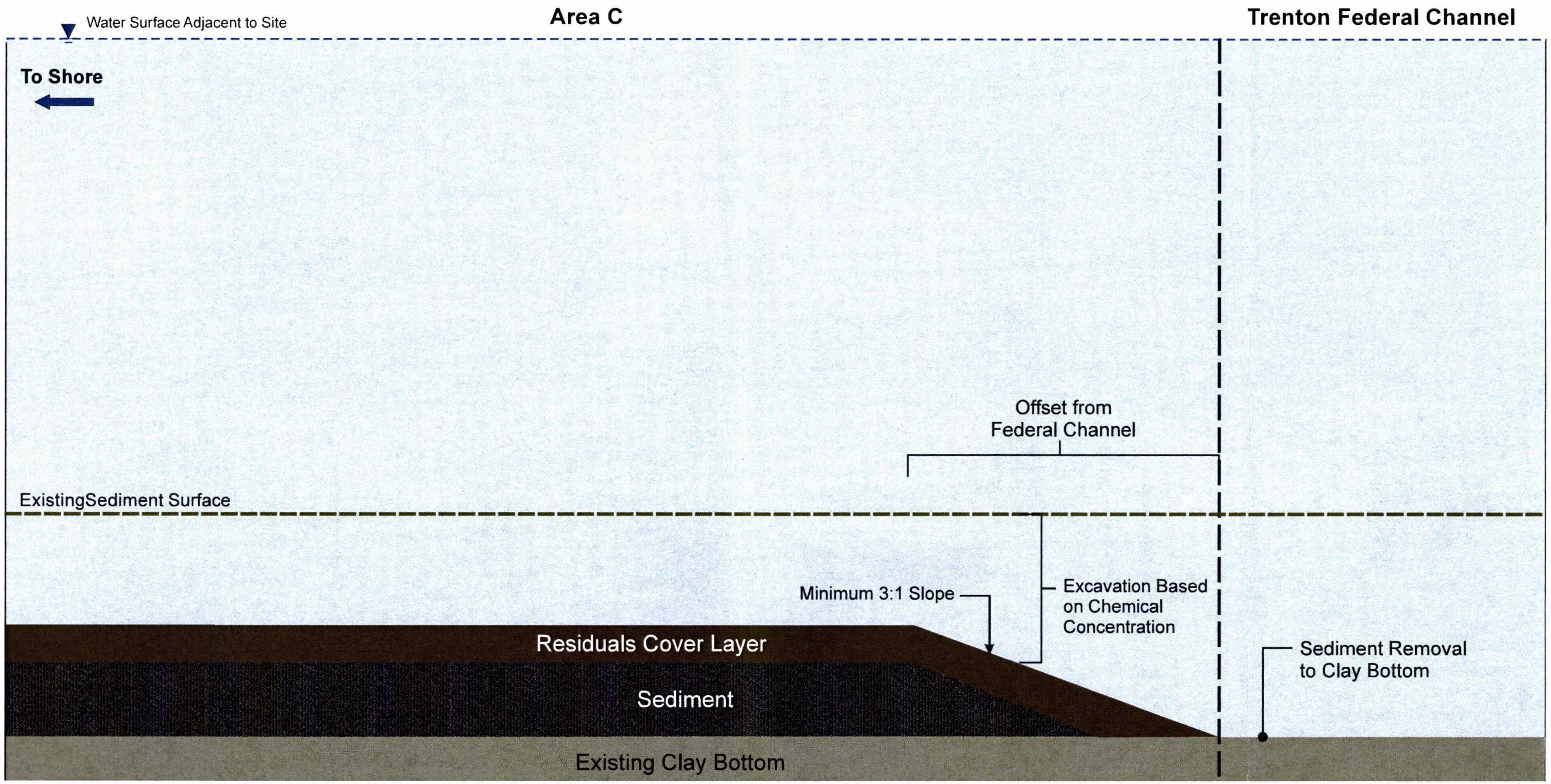
BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS

INTERIM MEASURE ALTERNATIVE 5 REMEDIAL COMPONENTS

ARCADIS

FIGURE
4-2a

08/04/2010 SYRACUSE, NY-ENV/CAD-DJHOWES, K.SARTORI
B0042929/0019/00020/CDR/42929G11.CDR



NOT TO SCALE

DRAFT FOR FEDERAL AND STATE REVIEW

Note:

1. The conceptual remedial components presented heron depicts interim measure Alternative 5 to be implemented within Areas B, C, D & F. The residual cover layer to be placed subsequent to removal in Area C will consist of a 6 inch layer of sand. No cap materials will be placed withinthe Federal Channel, Areas B, D & F.

2. Removal depth and residual cover layer shown are not to scale and should be considered conceptual.

BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS

INTERIM MEASURE ALTERNATIVE 5 REMEDIAL COMPONENTS

ARCADIS

FIGURE **4-2b**

08/17/2010 SYRACUSE, NY-ENV/CAD-DJHOWES
B0042929/0019/00020/CDR/42929G12.CDR

Appendices

ARCADIS

Infrastructure, environment, buildings

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BASF Corporation
Wyandotte, Michigan

Interim Measures Design Work Plan — Sediments

Appendix A - Project Footprint Development

BASF North Works

August 2010

Introduction

This appendix to the *Interim Measure Design Work Plan* (IMDWP) for the BASF North Works property located in Wyandotte, MI (the Site) describes delineation of the remediation footprint for the interim measure (IM) alternatives. Data used to develop the project remediation footprint were identified based on considerations of which chemical concentrations are locally elevated relative to background levels, which chemicals are correlated with benthic community assessment and toxicity endpoints, whether depositional patterns reflect fine sediment depositional patterns, and geochemical considerations. The steps in this analysis and the results for each parameter group are described in this appendix.

Decision Tree

Figure A-1 provides a conceptual diagram of the decision process used to establish the drivers for the project footprint. The process was applied to each parameter group and constituent on list of target analytes. Overall, the Site sediment investigations have resulted in a dataset that includes 23 inorganics (including total cyanide and the Michigan 10 metals), 17 volatile organic compounds (VOCs), 14 semi-volatile organic compounds (SVOCs), 16 polycyclic aromatic hydrocarbons (PAHs), three polychlorinated biphenyls (PCB) Aroclors (1248, 1254, and 1260), one pesticide (4,4'-dichlorodiphenyldichloroethylene [4,4'-DDE]), and conventional water quality parameters (bulk sediment pH, total organic carbon [TOC], total sulfide, and grain size). Additional parameters were measured in a subset of samples used for benthic community assessments and toxicity testing, including chloride, ammonia, dissolved oxygen, and water pH.

The decision tree consists of ten decision points grouped into three main categories: 1) Univariate Evaluations (i.e., statistical comparisons to upstream chemistry); 2) Association with Toxicity and Benthic Community Metrics (i.e., statistical correlation with biological endpoints); and 3) Other Site-Specific Factors (i.e., depositional patterns and potential bioavailability). A constituent was included as a potential footprint driver if it triggered a decision point in each category.

Univariate Evaluations

The term univariate refers to the idea that evaluations are performed on one variable at a time. The univariate evaluations were based on the results of the background screening analysis applied to each constituent. A detailed summary of the methods and results of the background screening analysis for the Phase II Sediment Investigation is provided in the Phase II Sediment Investigation: Data Summary Report (ARCADIS 2009). If the background dataset included one or more statistically significant outliers, a background screening level (BSL) was calculated both including and excluding the outlier(s) in order to assess the importance of the outlier(s) in the overall decision framework. Because the Site is located downstream of an urban industrial setting with many ongoing sources, surface sediment quality adjacent to the Site is assumed to be approximately the same as upstream conditions if there are no Site-related sources. An IM should be designed to achieve a realistic goal relative to upstream conditions. The project footprint for remediation (discussed in Section 3 of the IMDWP) is guided first by the magnitude and spatial extent of constituents that exhibit concentrations elevated above upstream levels.

Sediment samples collected upstream of the Site in October 2008 were evaluated to establish the ranges and distribution of constituent concentrations that are representative of background sediment quality. For each constituent, the upstream dataset consists of as many as 69 samples collected from 16 locations at depths ranging from the sediment surface to 8 feet below sediment surface (ft bss). Between two and six co-located core samples representing different depth intervals were available for each sample location. The complete upstream dataset (all constituents, locations, and depth intervals) consists of 3,700 sample results for constituents with sufficient data to calculate BSLs (i.e., $n \geq 8$ and detects ≥ 5). By comparison, the Site dataset consists of as many as 130 samples collected from 30 locations at depths ranging from the sediment surface to 9.5 ft bss. Between two and seven co-located core samples representing different depth intervals are available for each sample location and approximately 7,300 sample results are available for comparison to BSLs. The distribution of data by depth interval is comparable for upstream and Site datasets as noted below:

Depth Interval	Upstream Dataset	Site Dataset
0 to 1 ft	46%	46%
1 to 3 ft	22%	23%
> 3 ft	32%	31%

Therefore, the initial screening (Step 1) involved a point-by-point comparison of the Site data from all depths to a BSL that also represents all depths.

Step 1. Point-by-Point Screening to BSL

Table A-1 summarizes the BSLs that were established for each constituent and the number of exceedances among shallow sediment samples (i.e., start depth = 0 ft bss) and the maximum of co-located sediment core samples. The following observations are noted based on the results of the BSL screening step:

- A sufficient number of detects are available to generate BSLs for 60 constituents, of which the upper bound for six constituents is represented by two BSLs due to the presence of at least one statistically significant outlier (total sulfide, benzo(b)fluoranthene, pyrene, ethylbenzene, isopropylbenzene, and total xylenes). Thus, evaluations were performed using 66 BSLs for 60 constituents.

- Nine constituents (SVOCs and VOCs) were not detected and, therefore, were excluded from the list of potential drivers.

- Eleven constituents with sufficient detects were excluded because there were no exceedances among either surface or core maximum samples: eight metals (antimony, cadmium, chromium, cobalt, copper, nickel, vanadium, and zinc), total sulfide (BSL including outliers), 4,4-DDE, and Aroclor 1248.

- Four constituents were retained due to an exceedance of a core maximum concentration without a corresponding exceedance in any surface samples: barium, total sulfide (excluding outliers), Aroclor 1254, and 2-methylnaphthalene.

- For six constituents with statistically significant outliers, excluding the outliers in the BSL calculation resulted in only one adjustment – an inclusion of total sulfide in the list of potential drivers; the other five constituents had at least one exceedance of the BSL even with the upstream outliers included, so the result was insensitive to outliers in the upstream dataset.

- Forty-nine of 60 (82%) of the constituents from the October 2008 sediment investigation were retained as potential remediation footprint drivers after Step 1.

- Three constituents were retained due to single exceedances of the BSL, which occurred in the surface sample: aluminum, mercury, and silver.

Steps 2 and 3. Hypothesis Testing of Central Tendency and Upper Tails

Even if the distribution of a constituent is the same in upstream and Site locations, there is a high probability of observing at least one exceedance of a BSL during Step 1 by random chance. The probability of observing an exceedance increases as the sample size (i.e., number of comparisons to the Site dataset) increases. Therefore, while Step 1 is a reliable tool for screening out constituents that are highly unlikely to be attributable to Site activities, further evaluation steps are needed to refine the list of constituents that should ultimately be retained as potential footprint drivers. Consistent with United States Environmental Protection Agency (USEPA) guidance on background screening analysis (USEPA 2006; 2009; 2010), the distributions were evaluated for differences in both the central tendency (Step 2) and upper tails (Step 3) at an $\alpha=0.05$ significance level. Table A-2, which is based on Table 8 of the background analysis (ARCADIS 2009), provides results for both tests for all constituents using data from all depth intervals. Key findings are noted below:

- Thirty-two of 49 constituents retained in Step 1 were excluded following the hypothesis testing of Steps 2 and 3; 17 constituents were retained, providing additional evidence that concentrations of selected constituents are elevated above upstream levels at the Site.

- Four constituents are elevated at the Site based on comparisons of both the central tendency and upper tails of the distributions: beryllium, bulk sediment pH, total cyanide, and phenol.

- Thirteen constituents exhibit elevated concentrations in the upper tails but not the central tendency of the distribution, including five metals (aluminum, arsenic, lead, selenium, and thallium), six PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, fluoranthene, and indeno(1,2,3-cd)pyrene), dibenzofuran, and 3- and 4-methylphenol.

- Phenol was detected in 84 of 130 (65%) of Site samples, compared to seven of 69 (10%) upstream samples.

Table A-3 provides results for hypothesis tests for all constituents using data from surface sediment (i.e., start depth = 0 ft bss and end depth ≤ 1 ft bss). Surface sediment is more likely to be representative of the biologically active zone and corresponds with samples used to assess benthic toxicity and benthic community health. Sample sizes for most constituents ranged from 50 to 56 for Site samples and

18 for upstream samples, with the exception of 4,4-DDE and PCB Aroclors, which had 29 Site samples and 18 upstream samples. Key findings are noted below:

- Constituents that are elevated based on both the hypothesis testing with all depths (summarized above) and the hypothesis testing with surface sediment include: four metals (aluminum, arsenic, beryllium, thallium), total cyanide, bulk sediment pH, six PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, fluoranthene, and indeno(1,2,3-cd)pyrene), dibenzofuran, and 3- and 4-methylphenol.

- Constituents that are elevated in the evaluation of all depths, but not in surface samples, include: lead (upper tail only), selenium (upper tail only), and phenol (both central tendency and upper tail).

- Constituents that are elevated in the evaluation of surface samples, but not all depths, include: mercury, total sulfide, 4,4-DDE, total PAH, di-n-octyl phthalate, benzene, isopropylbenzene, toluene, and xylenes. In each case, only the comparison of central tendencies indicates that concentrations are elevated in Site surface sediment; differences in the upper tails are not statistically significant (α=0.05). The frequency of detection is similar for Site and upstream samples and generally high (i.e., > 50%). One exception is di-n-octyl phthalate, which was detected in 8 of 56 (14%) Site samples and 6 of 18 (33%) upstream samples.

Association with Benthic Toxicity and Benthic Community Metrics (Statistical Correlation with Biological Endpoints)

Benthic toxicity testing and benthic community investigations were conducted at select upstream and Site locations using surface samples (i.e., generally 0 to 0.5 ft bss), which are most likely to be indicative of the biologically active zone. Figure A-2 shows the locations of the upstream and Site sample locations used for toxicity testing and benthic community assessments. A constituent was determined to be a potential local stressor to the aquatic ecosystem if it was associated with variance in one or more of the benthic community assessment and/or toxicity endpoints.

Associations between sediment chemistry and benthic toxicity or benthic community metrics requires establishing a dataset of paired results for multiple sampling locations in both upstream and Site areas. For the sediment chemistry data describe above, the full list of constituents is too large to conduct multivariate analyses including multiple regression analysis and cluster analysis. To reduce the potential for errors associated with overparameterization of statistical models, an initial correlation analysis was conducted for each parameter group. Table A-4 summarizes the Spearman rank correlation coefficients calculated for select constituents grouped as metals, PCBs and pesticides, and VOCs. Spearman rank correlation is a non-parametric analogue to Pearson correlations (performed on ranks instead of values), and reduces potential bias introduced by nondetects and outliers. Constituents that were initially excluded from the multivariate statistical analysis due to high correlations (i.e., rho (ρ) > 0.7) with other constituents are noted with "X". For metals, five of 17 constituents were excluded: barium, cadmium, cobalt, nickel, and silver. For PCBs, Aroclors 1248 and 1254 were excluded because they were highly correlated (ρ > 0.9) with Aroclor 1260. A single pesticide (4,4-DDE) was also retained and is expected to exhibit similar results to the PCBs. For VOCs, five of 11 constituents were excluded as noted in Table A-4. A separate analysis of PAHs suggested that total PAH could be used as a grouping variable for all PAHs as well as dibenzofuran. Other constituents that were retained include bulk sediment pH and phenol. Key explanatory variables identified with this initial list of variables are identified in this report as "primary variables", and corresponding correlated variables are identified as "correlated variables".

Concentration maps were developed using inverse distance weighting (IDW) to interpolate concentrations between sample transects along the Site. Point sample data were collected in transects, so along-transect distances between samples were much smaller than between-transect distances. To address this difference, an elliptical window with a 3-to-1 anisotropy was used to determine which samples should inform any pixel. The ellipse was oriented at a fifteen-degree azimuth to coincide more closely with the flow of the river, which varied from ten to twenty degrees azimuth along the Site. The power used for the IDW formula was optimized for each analyte, to minimize the error in the interpolation. Because fewer samples were collected in upstream locations, constituent concentrations at locations selected for benthic toxicity testing were estimated from the nearest available sediment sampling location. Examples of IDW interpolations are given in Figures A-3 to A-8 for interpolations of surface sample concentrations of aluminum, arsenic, beryllium, thallium, percent fines, bulk sediment pH, phenol, total cyanide, total PAH, and toluene. These constituents are discussed in subsequent sections on potential footprint drivers.

The complete dataset used in the statistical analysis of the benthic community metrics is provided in a series of tables as outlined below:

- Table A-5 – Benthic Organisms Identified from 2009 Site Investigation – gives the full counts of all organisms identified to define benthic community metrics for each Site and upstream sampling station.

- Table A-6 – Benthic Community Metrics by Sampling Location – values for 10 metrics used to quantify aspects of community structure and function that change in predictable ways with increased human influence and/or perturbation.

- Table A-7 – Physicochemical Variables Measured at Benthic Sample Locations – results for parameters measured concurrently with the benthic community sampling from 10 Site locations and 11 upstream locations included the following: chloride (milligrams per kilogram [mg/kg]), total ammonia (milligrams per liter), bulk sediment pH, TOC (mg/kg), grain size (% fines), flow (ft/sec), turbidity (nephelometric turbidity units), conductivity (mS/cm), surface water pH, temperature, and water depth (ft).

- Table A-8 – Analytical Results for Sediment Samples – concentrations of sediment chemistry variables estimated for each of the 21 sampling locations used in the multivariate analysis. Original sample locations for nearest assignments to associate with upstream stations are noted. SU-U11 is nearest to five different locations, which introduces uncertainty by likely underestimating the variance in upstream sediment chemistry.

Although chemistry and water quality parameters were not measured in the sediment samples that comprise the full Site dataset, the sample sizes are sufficient to conduct a multivariate analysis of the full constituent list based on results for these 21 sampling locations (11 upstream and 10 Site). Split samples from 12 of the 21 locations were used to also conduct 10-day whole sediment survival and growth toxicity testing with *Chironomus dilutus* and *Hyalella azteca* to assess differences in benthic toxicity between upstream and Site locations. The four of 11 upstream locations used in the toxicity testing are BC-U04, BC-U10, BC-U15, and BC-U16; the eight of 10 Site stations include all but BC-T27-50 and BC-T28-125 (see Figure A-2).

A December 2009 report prepared by the Great Lakes Environmental Center (GLEC) presents a summary of the toxicity data and hypothesis test results (GLEC 2009). Summary statistics and Spearman rank correlation coefficients are summarized in this appendix as Tables A-9 and A-11 for *Chironomus* and Tables A-10 and A-12 for *Hyalella*. The survival and biomass metrics are highly correlated for each indicator species (i.e., ρ > 0.9 for *Chironomus* and ρ >0.95 for *Hyallela*); therefore, similar results for multivariate statistics are expected.

Benthic community taxa counts and associated metrics were used in the multivariate analysis. A total of 10 metrics were initially selected to reflect metrics that are widely used and recognized by state and federal agencies as well as the applicability to Site conditions (i.e., deep water sediment). These include richness (number of individuals, total taxa, and biomass), composition (percent *Oligochaeta*, *Chironomidae*, and *Insecta*), tolerance (tolerance index and percent dominant taxon), and diversity and evenness measures. The results of the statistical analysis are as follows:

Assessment Endpoint		**Measurement Endpoint**			
		Correlation	**Hypothesis Tests**	**Multiple Regression**	**Similarity Indices**
Benthic Metrics					
Richness	Total Individuals	X	X	X	
	Biomass	X	X	X	
	Total Taxa	X	X	X	
Composition	% Oligochaeta	X	X	X	
	% Chironomidae	X	X	X	
	% Insecta	X *			
Tolerance	% Dominant Taxon	X *			
	Tolerance Index	X *			
Diversity	Diversity Index	X *			
	Evenness Index	X *			
Assemblage Data					
Taxa Counts					X

Due to the high correlation among metrics (Spearman ρ > 0.7), five metrics with the asterisk "X*" could be excluded without loss of information. The correlation matrix for the metrics is given below:

Statistical Analysis	Benthic Metrics	Benthic Metrics Included in Statistical Analysis				
		Total Individuals	**Biomass**	**Total Taxa**	**% Oligochaeta**	**% Chironomidae**
Included	Total Individuals	1.00				
	Biomass	0.35	1.00			
	Total Taxa	0.28	0.58	1.00		
	% Oligochaeta	0.33	-0.31	-0.65	1.00	
	% Chironomidae	-0.01	0.05	0.52	-0.56	1.00
Excluded due to Correlation	% Insecta	-0.06	0.16	0.64	**-0.70**	**0.95**
	% Dominant Taxa	-0.05	-0.50	**-0.80**	**0.71**	-0.25
	Tolerance Index	0.49	-0.24	-0.47	**0.79**	-0.26
	Diversity Index	0.11	0.57	**0.92**	**-0.75**	0.51
	Evenness Index	-0.31	0.19	0.39	**-0.68**	0.20

Additional tables and figures corresponding to the analysis of the benthic community data are presented below along with observations.

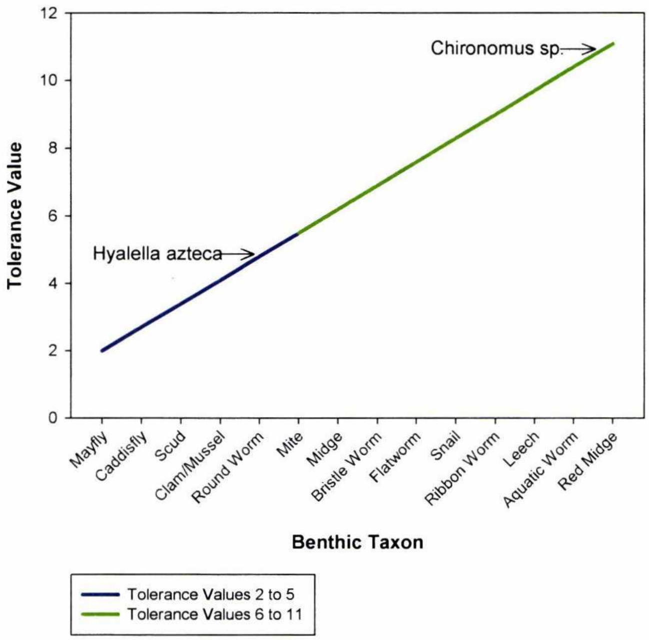


Figure A-9. Conceptual relationship between general benthic classifications and associated tolerance values.

Tolerance values (TVs) are standard benthic metrics used by most regulatory agencies to assess benthic community condition. They represent the relative sensitivity to general (non-specific) perturbation (USEPA 1999), which often includes organic and chemical pollution. TVs are typically ascribed at the genus/species level, with values ranging from 0 (most sensitive to stress) to 11 (most tolerant to stress). Because Michigan does not have state-wide TVs, the TVs used in this assessment were based on Illinois TVs due to similarities in geography as well as completeness of scores.

Figure A-9 provides a "conceptual" or "generalized" summary of "average" or "typical" taxonomic scores for higher level classification groups. Within these groups, there could be a wide range of TVs. TVs were developed primarily for organic pollution (nutrients, dissolved oxygen, etc.), however, they have since been used to detect other possible stressors. The relationship between pH and tolerance is unclear. TVs vary some by state, and values for *Hyalella* are similar between Illinois Environmental Protection Agency (EPA) and Ohio EPA (5 and 4, respectively) but higher for New York Department of Environmental Conservation (8). TVs for *Chironomus* are almost always 10 or 11.

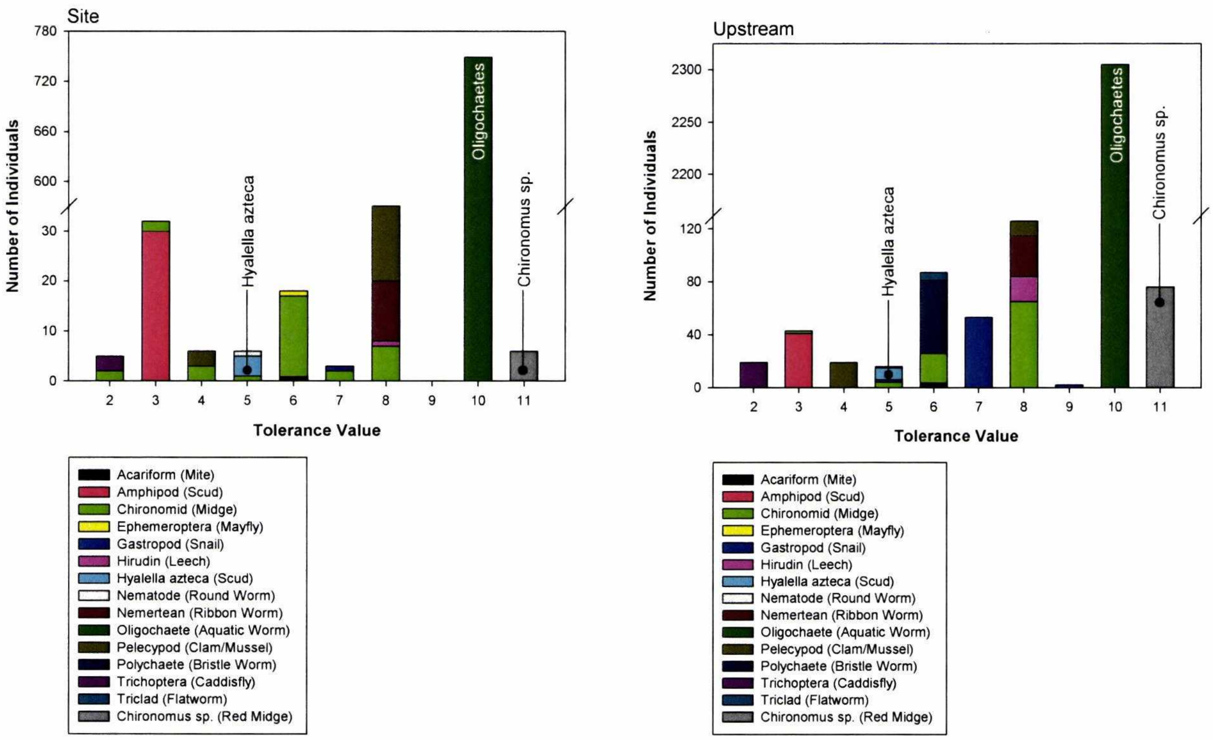


Figure A-10. Total number of individuals by tolerance level. Left = Upstream locations (n=11); Right = Site locations (n=10).

- Note that the scale for the y-axis (number of individuals) ranges from 0 to 2,300 for upstream with a break at 125, whereas the scale ranges from 0 to 780 for Site with a break at 35.
- The benthic community at both Site and upstream locations was comprised primarily of organisms tolerant to stress (87% Oligochaetes at Site and 84% Oligochaetes upstream).
- The genus *Chironomus sp.* was also identified, which may contain the species *Chironomus dilutus*, and has a TV of 11.

- *Hyalella azteca* was present in limited numbers (0.5% at Site and 0.3% upstream) and has a tolerance value of 5, which indicates sensitivity to stress.

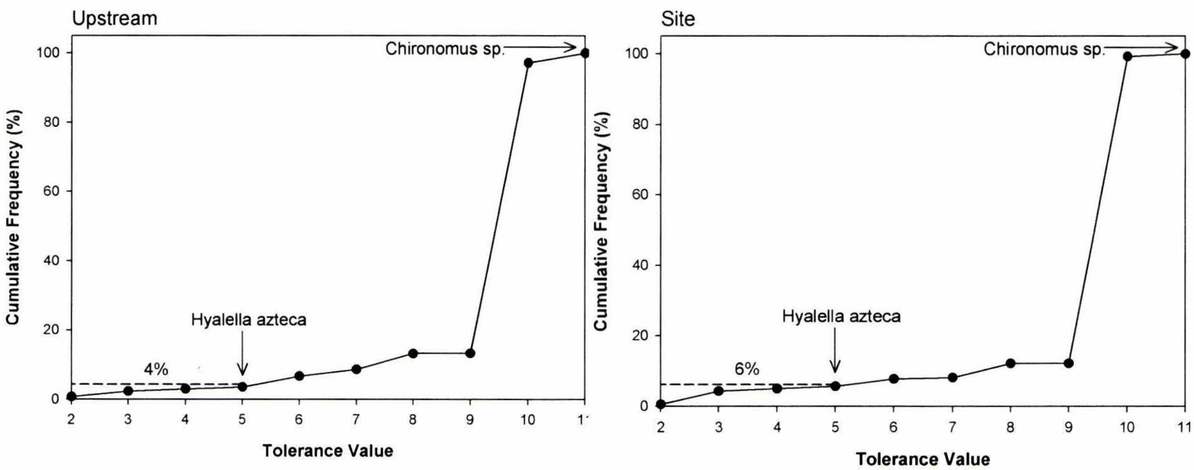


Figure A-11. Cumulative frequency distribution of total organisms by tolerance level. Left = upstream locations (n=4); Right = Site locations (n=8).

- 6% of the Site organisms and 4% of the upstream organisms had a TV similar to or less than *Hyalella azteca* (TV = 5).
- The sharp increase in cumulative frequency at both Site and upstream areas is due to the relatively large number of Oligochaetes (TV =10).

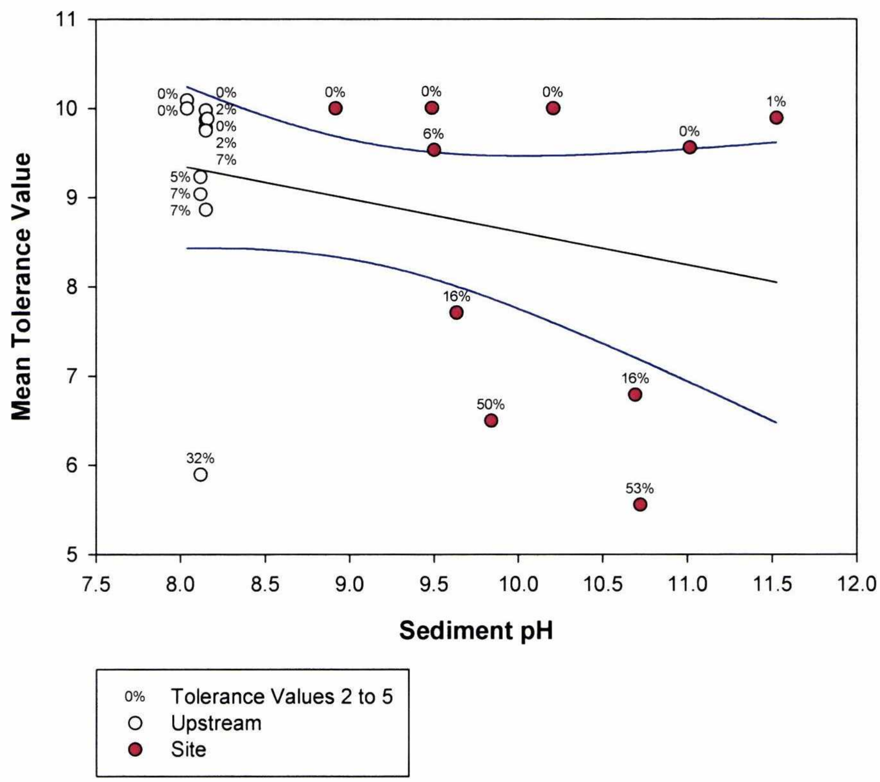
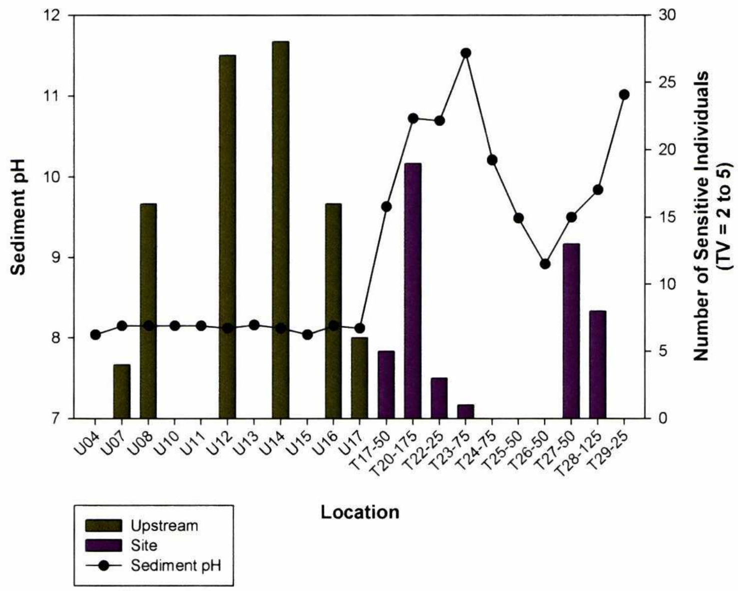


Figure A-12. Relationship between bulk sediment pH and Mean Tolerance Value. Labels show relative percent of organisms comprised of more sensitive taxa (TV = 2 to 5).

- No relationship between bulk sediment pH and tolerance value is apparent.
- Higher and lower TVs are reported across the range of bulk sediment pH for both Site and upstream locations.
- Points represent the mean TV among all organisms identified at the location. Figure A-11 shows that most stations are dominated by the more tolerant species, which will shift the value of the mean up.



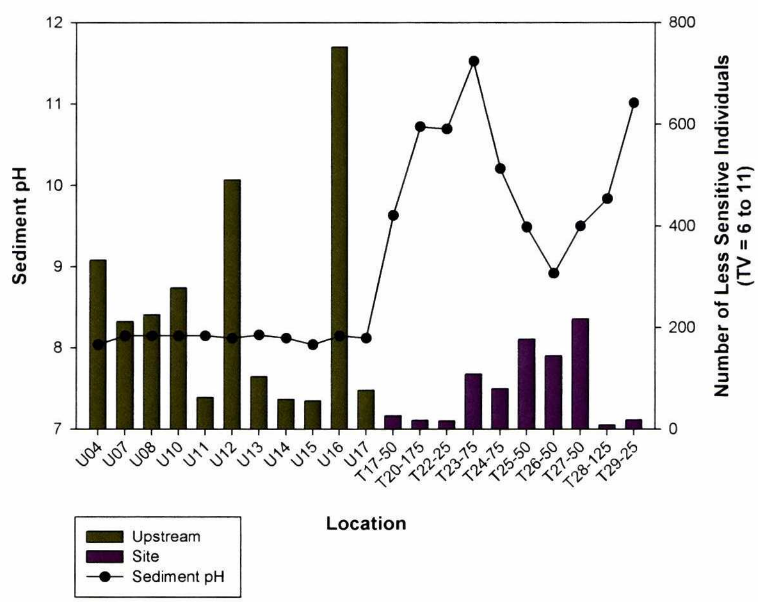


Figure A-13. Bulk sediment pH and number of individuals per taxa group by sample location. Top = more sensitive taxa (TV = 2 to 5); Bottom = less sensitive taxa (TV = 6 to 11).

- Upstream locations are highly variable with no apparent relationship – the numbers of sensitive and less sensitive individuals are both high and low with relatively constant bulk sediment pH.

- Site locations are also highly variable. As bulk sediment pH increases, the number of sensitive individuals increases while the number of less sensitive individuals decreases.

Steps 4, 6, and 7. Multiple Regression Analysis

Results of multiple regression analysis are reported in Table A-13 for benthic community metrics and Table A-14 for benthic toxicity endpoints. Table A-15 presents a side-by-side comparison of the primary explanatory variables for all regression models as well as the correlated variables. The following observations are noted:

- Regression models for benthic community metrics are generally poor (adjusted $R^2 \leq 0.4$) for all but percent *Chironomidae* (adjusted $R^2 = 0.8$, $p < 0.01$). There is high uncertainty in establishing remediation footprints based on primary explanatory variables of models that explain less than 50% of the variance (i.e., bulk sediment pH, zinc, total PAH, chromium, ammonia, and correlated variables).

- The two primary variables that explain the variance in percent *Chironomidae* are 4,4-DDE ($p<0.01$) and chloride ($p<0.05$). Correlated variables include chromium, copper, lead, and Aroclor 1260. Of these variables, **4,4-DDE** and **lead** screened in as a potential footprint driver based on Steps 1 through 3 (see Figure A-1).

- Regression models for benthic toxicity are generally very strong with adjusted R^2 values between 0.6 and 0.8.

- **Aluminum** occurs as a primary explanatory variable in multiple models for benthic toxicity. Aluminum is a potential footprint driver along with the following correlated variables that screened in after Step 3: **arsenic** (Pearson $r^2 = 0.5$), **beryllium** ($r^2 =$ 0.5 to 0.8), **mercury** ($r^2 = 0.7$), and **thallium** ($r^2 = 0.7$).

- Two primary explanatory variables for *Chrionomus* biomass are **4,4-DDE** ($p<0.01$) and **chloride** ($p<0.05$), both of which show a positive association (i.e., increasing concentrations yield increasing biomass). Thus, the relationship is not indicative of toxicity to a more tolerant benthic species. Aluminum is also a primary explanatory variable ($p<0.01$) that exhibits a negative association and is moderately correlated with additional metals that screened in after Step 3 as noted above.

- The primary explanatory variable for *Hyalella* biomass is lab water pH ($p<0.05$) (see Figure A-14), which is moderately correlated in the regression model with the following additional variables that screened in after Step 3: **bulk sediment pH** ($r^2 = 0.6$), **phenol** ($r^2 = 0.6$), and **total cyanide** ($r^2 = 0.6$).

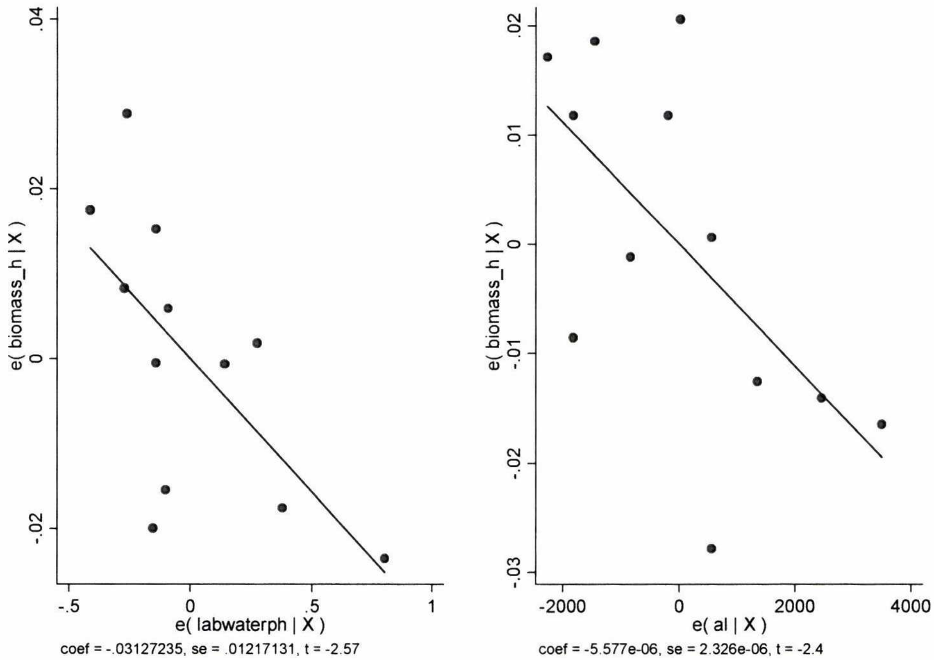


Figure A-14. Partial correlation plot for regression analysis for *Hyalella* biomass with key explanatory variables - lab water pH (left) and aluminum (right).

- The primary explanatory variables for *Hyalella* survival are **toluene** ($p<0.01$) and **thallium** ($p<0.05$), both of which screened in after Step 3. Thallium is moderately correlated in the regression model with the following additional variables that screened in after Step 3: **arsenic** ($r^2 = 0.8$), **lead** ($r^2 = 0.5$), and **mercury** ($r^2 = 0.7$).

Steps 5 and 7. Similarity Index (Cluster Analysis)

Agglomerative hierarchical clustering is a type of multivariate data analysis in which a relationship between sampling units (e.g., sediment stations) can be established by reducing a large number of variables (e.g., abundance of various organisms) to a coefficient that represents a degree of dissimilarity between sampling units. Although there are many different methods for calculating coefficients and establishing clusters, each method is generally applied in the following sequence:

1. Calculate a matrix of dissimilarities between all pairs of sampling units.

2. Form the first cluster between two sampling units with the smallest dissimilarity.

3. Calculate dissimilarities between the first cluster and the remaining sampling units.

4. Form the second cluster between the first cluster and the sampling unit with the smallest dissimilarity to the first cluster.

5. Continue until all sampling units are linked in clusters.

The data for each sampling unit consist of values for multiple variables. The dissimilarity between every pair of sampling units is measured by calculating a coefficient that accounts for differences in values for each variable. For this analysis, the sampling unit is a Site or upstream sediment sampling location and the variables represent benthic invertebrate species composition (abundance data organized at a variety of taxonomic levels, including species, family, and order) as well as toxicity results.

The metric of dissimilarity used in this analysis is the Euclidean coefficient:

$$\delta_{jk} = \sqrt{\sum_{i=1}^{p} \left(y_{ij} - y_{ik}\right)^2}$$

where,

δ_{jk}	=	dissimilarity between the j^{th} and k^{th} sediment station
y_{ij}	=	abundance of the i^{th} species for the j^{th} sediment station
y_{ij}	=	abundance of the i^{th} species for the k^{th} sampling station

The approach yields a coefficient for each sediment station that ranges from 0.0 (indicating no dissimilarity, or all attributes with identical values) to 1.0 (indicating complete dissimilarity, or no species compositions in common). The coefficients can be presented as a dendrogram, which is a tree-like diagram that shows the dissimilarity coefficients for each sampling unit. In this analysis, sampling stations that are linked in the same cluster exhibit the greatest similarities in species composition or benthic toxicity results. Clusters that have the shortest links (or distances) are most similar. As with multiple regression analysis, the key factors that contribute to the clustering patterns are noted, and the strength of the overall "fit" of the model is expressed in terms of a correlation coefficient, ρ.

Figures A-15 and A-16 present the dendrograms based on toxicity results for *Chironomus* and *Hyalella*, respectively. For *Chironomus,* upstream and Site stations cluster together ($p=0.10$) and show no group structure ($p=0.23$). This suggests that toxicity to *Chironomus* is similar for many upstream and Site locations. For *Hyalella*, upstream and Site stations cluster separately ($p=0.02$) and do show group structure ($p<0.05$), corroborating the assumption that *Hyallela* is a more sensitive test species. In addition, the following observations are noted:

- Similarity indices linking *Hyalella* toxicity results to sediment chemistry indicate that the link between both groups of variables is weak (i.e., no association in multivariate pattern, $p=0.15$). The highest correlation ($\rho=0.54$) is achieved based on the combined contributions of **chloride**, **selenium**, **aluminum**, **4,4-DDE**, and **toluene**.

- Similarity indices show agreement in multivariate pattern between toxicity and benthic community metrics ($p=0.04$).

- The multivariate analysis using similarity indices does not result in any changes or additions to the list of constituents that may be footprint drivers.

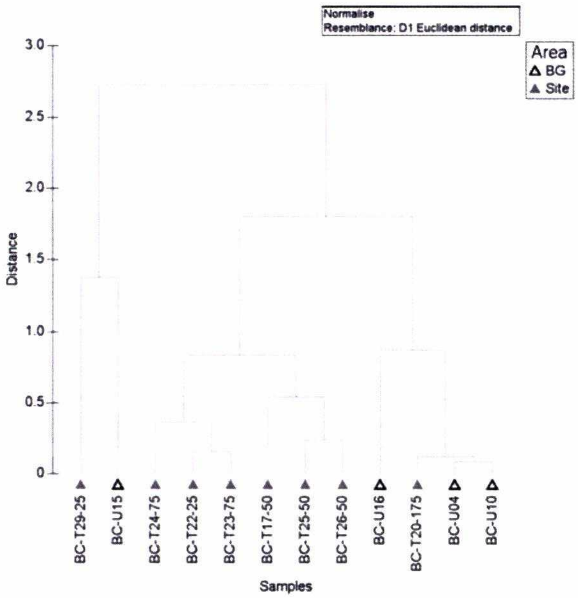


Figure A-15. Dendrogram based on Survival and Growth of *Chironomus*.

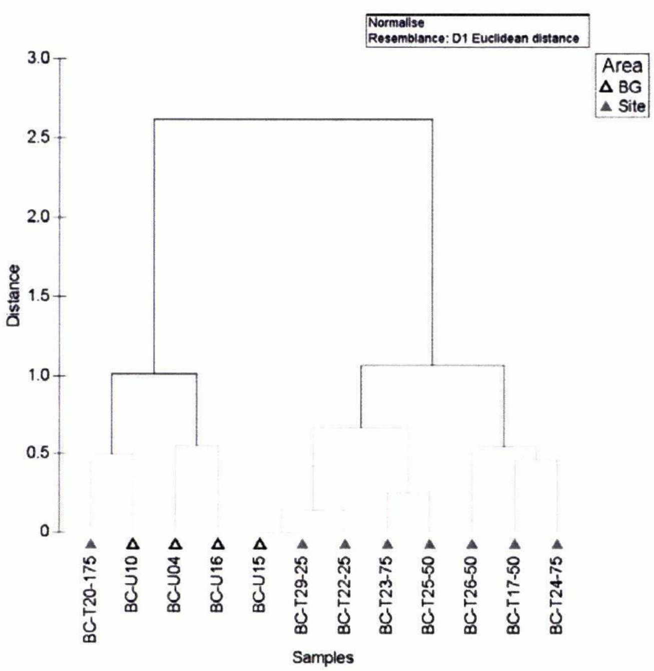


Figure A-16. Dendrogram based on Survival and Growth of *Hyalella*.

Chloride

Chloride was not one of the chemistry parameters measured in the Site sediment samples that comprise the full Site dataset. Chloride was measured in surface sediment samples (0 to 0.5 ft bss), each of which was a composite of four to five sub-locations. Chloride was included in the multiple regression analysis and similarity indices used to determine the key factors that explain the variance in benthic community metrics and toxicity results. Using the full dataset (all 21 stations), the statistical analysis of the benthic community metrics suggest that chloride is a key factor for the following dependent variables in the regression models:

- Percent *Oligochaetes* (R^2=0.4, p=0.02) – chloride is the top ranked variable and the coefficient is *negative*, indicating higher chloride concentrations are associated with lower percent Oligochaetes. The inverse relationship suggests that chloride is not a driver for benthic toxicity.
- Percent *Chironomidae* (R^2=0.8, p<0.001) – chloride is the second highest ranked variable (after 4,4-DDE) and the coefficient is positive, indicating higher chloride concentrations are associated with higher percent chironomids (i.e., a potential adverse effect).
- Total taxa (R^2=0.3, p=0.02) – chloride is the third highest ranked variable (after zinc and bulk sediment pH) and the coefficient is positive, indicating concentrations are associated with greater abundance of taxa, which suggest that chloride is not a driver for benthic toxicity.

Multiple regression analysis applied to the toxicity results also suggested that chloride may be a key factor for the following dependent variables:

- Biomass of *Chironomus* (R^2=0.8, p<0.001) – chloride is the third highest rank variable (after 4,4-DDE and aluminum) and the coefficient is positive, which suggests that chloride may be associated with an increased abundance of more tolerant species.

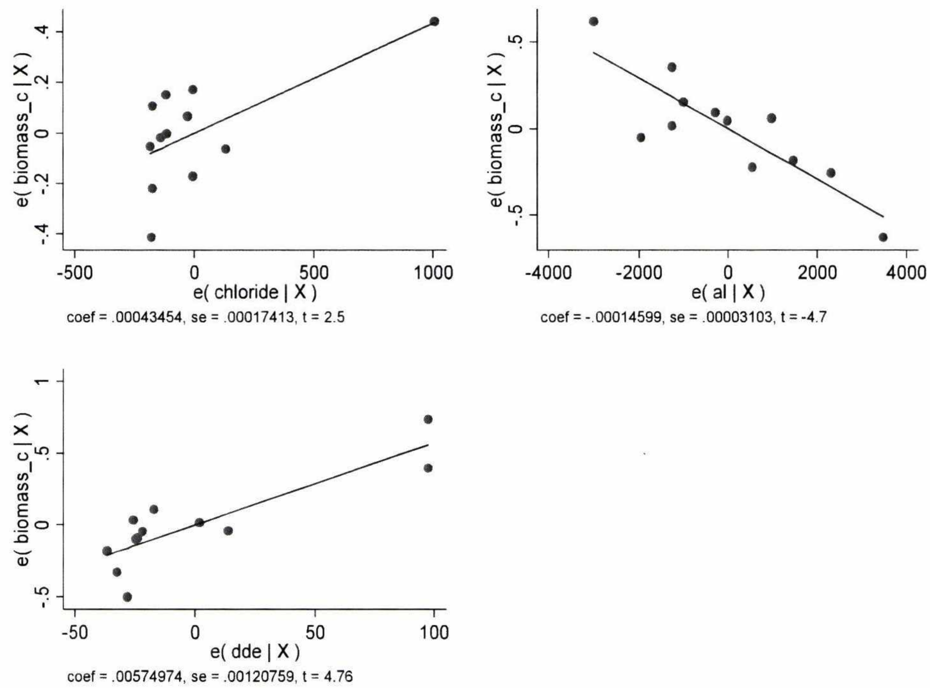


Figure A-17. Partial correlation plots for multiple regression model for biomass of *Chironomus*, including the outlier for chloride (BC-T20-125). Chloride is shown in the top left; aluminum is top right; 4,4 DDE is bottom left.

The partial correlation plot provided in Figure A-17 suggests that there is an outlier in the chloride/biomass relationship (sample collected from BC-T20-125). A reduced regression model that excludes the outlier suggests that chloride and 4,4-DDE are no longer significant predictor variables. Biomass for *Chironomus* (R^2=0.9, p<0.001) is most strongly associated with toluene, % fines, and river water temperature. The PRIMER software used to run the similarity indices requires complete data matrices to perform a calculation. Therefore, it is not possible to exclude just one parameter (e.g., chloride) from one sample (BC-T20-125). Instead, one must either exclude the chloride parameter altogether (from all samples), or exclude the sample with the outlier altogether (all parameters). Both approaches were evaluated as a form of sensitivity analysis.

The similarity index calculations with the outlier included yield an agreement in the multivariate patterns that suggests the following:

- Benthic community assemblage is best described by chloride and total PAH combined (ρ =0.51).

- Survival and growth of *Hyallela* are best described by chloride together with selenium, aluminum, 4,4-DDE, and toluene (ρ =0.54).

Without chloride, the results are:

- Benthic community assemblages are best described by total PAH (ρ = 0.53).

- Survival and growth of *Hyalella* are best described by selenium, aluminum, and 4,4-DDE (ρ = 0.54).

Without BC-T20-175, the results are:

- Benthic community assemblages are best described by total PAH combined (ρ = 0.55).

- Survival and growth of *Hyalella* is best described by ammonia, selenium, aluminum, 4,4-DDE, and toluene (ρ = 0.68). The best single explanatory variable is selenium (ρ = 0.51).

The sensitivity analysis suggests the single outlier for chloride determines whether or not chloride is an important explanatory variable for determining which stations exhibit similar results for benthic community metrics and benthic toxicity. It is more appropriate to interpret the results with the outlier excluded. The key explanatory variable for benthic community assemblage is total PAH, and the key explanatory variables for benthic toxicity (survival and growth of *Hyalella*) are selenium, aluminum, and 4,4-DDE. Excluding all of the results for BC-T20-175 provides a slight improvement in the overall fit of the model.

Multivariate Analysis Implications for Potential Footprint Drivers

Through Step 7 of the decision tree, the list of potential footprint drivers includes the following constituents:

- phenol (Figure A-18)
- bulk sediment pH (Figure A-19)
- total PAH (Figure A-20)
- total cyanide (Figure A-21)

- selected metals (Figure A-22): aluminum, arsenic, beryllium, lead, mercury, selenium, and thallium
- toluene (Figure A-23)

Selected constituents that exhibit moderate associations with toxicity are discussed below. Collectively, the multivariate analyses (both multiple regression and cluster analysis) suggest that the following variables that screened in through Step 3 are no longer potential footprint drivers: sulfide, dibenzofuran, di-n-octyl phthalate, benzene, isopropylbenzene, and xylenes.

Phenol

Phenol exhibited statistically significant differences between upstream and Site locations for all depths and surface samples, as well as greater than 50% exceedances of the BSL of 0.28 mg/kg. Phenol is also correlated with primary explanatory variables for regression models for biomass and survival of *Hyalella*. Accordingly, phenol was retained as a potential footprint driver.

Bulk Sediment pH

Bulk sediment pH exhibited statistically significant differences between upstream and Site locations for all depths and surface samples, as well as greater than 30% exceedances of the BSL of 10.5. Bulk sediment pH is also correlated with a primary explanatory variable for regression model for biomass of *Hyalella*. Bulk sediment pH is also among the primary variables for relatively weak regression models for benthic community metrics, including biomass (R^2 = 0.4), total taxa (R^2 = 0.4), and percent Oligochaetes (R^2 = 0.5). Accordingly, bulk sediment pH was retained as a potential footprint driver.

Total PAH

Total PAH exhibited a statistically significant difference between upstream and Site locations for surface sediment only (Table A-3). In addition, six individual PAHs were elevated above BSLs based on hypothesis testing for all depths and surface samples. For models that explain at least 50% of the variance in benthic toxicity and community metrics, total PAH is not a primary explanatory variable nor is it correlated with a primary variable. Nevertheless, concentrations are elevated well above the BSL of 176 mg/kg at transects T-19, T-21, and T-25 (Figure A-7) and total PAH was retained as a potential footprint driver.

Total Cyanide

Total cyanide exhibited more than 30% exceedances of the BSL of 5.8 mg/kg in both surface sediment and core maximum samples (Table A-1), and hypothesis testing (both central tendency and upper tail tests) suggests that concentrations are elevated among surface samples and all depths combined. Multivariate analyses did not identify total cyanide as a primary explanatory variable (or correlate) for most toxicity endpoints. Total cyanide did exhibit a weak association with lab water pH (r^2=0.6), which was the primary explanatory variable for *Hyalella* biomass. Therefore, although the evidence is weak, total cyanide was retained as a potential footprint driver.

Toluene

Although there was just one exceedance of the toluene BSL of 0.33 mg/kg among 56 surface samples and three exceedances among the 47 core maximum concentrations (Table A-1), toluene exhibited a statistically significant difference between upstream and Site locations for surface sediment (Table A-3). Toluene is the primary explanatory variable for the regression model for survival of *Hyalella*, and is also among the key variables linking *Hyalella* toxicity results to sediment chemistry in the cluster analysis.

4,4-DDE

4,4-DDE appears to be elevated in surface sediment (Table A-3), but not all depths (Table A-2). 4,4-DDE is a primary explanatory variable for several endpoints of toxicity including percent *Chironomidae* and biomass of *Chironomus*, however, its relationship is mixed. Upon removing an outlier for chloride, the association is weak, and favors toluene and percent fines. Accordingly, 4-4 DDE was excluded as a potential footprint driver, given stronger associations are evident between toxicity endpoints and other constituents.

Other Site-Specific Factors (Steps 8 to 10)

A variety of Site-specific factors may contribute to the differences in sediment quality between upstream and Site sampling stations. Spatial heterogeneity in sediment deposition due to variations in flow velocity can strongly influence the geochemical environment and corresponding chemical speciation and bioavailability. Associations with both physical parameters (e.g., sediment thickness, percent fines) and chemical factors (e.g., aluminum concentrations) were assessed using maps of spatially interpolated results as well as correlation analysis of paired results.

Total cyanide is not strongly correlated with other inorganics or physical parameters associated with a depositional environment (e.g., percent fines, sediment thickness). Elevated concentrations in Site sediment are not necessarily indicative of increased risk to the aquatic ecosystem if the constituent is present in a form that is not readily bioavailable. As discussed in Appendix B, cyanide in Site sediments is likely to be present in iron-cyanide complexes that are stable and exhibit low bioavailability. Accordingly, total cyanide was excluded from the list of footprint drivers (Figure A-1, Step 10). The metals that screen in as potential footprint drivers through Step 7 exhibit moderate to high correlations with each other and other metals (see Table A-4) and are also moderately correlated with percent fines (Spearman ρ=0.5), exhibiting very similar spatial gradients as shown in Figure A-3. For all depths combined, the hypothesis testing results suggested that most of the metals concentrations differed from upstream concentrations in the upper tails rather than the central tendency (Table A-2). For surface samples, the opposite pattern was observed – distributions of metals differed based on the central tendency test rather than the upper tails for all but beryllium and thallium, which appeared elevated based on both tests. Figure A-3 shows that metals exhibit a spatial gradient of progressively increasing concentrations with increasing percent fines among stations towards the southern transects. Together, these factors suggest that variability in metals concentrations are influenced mainly by differences in depositional patterns of sediment throughout the system. Therefore, because the potential for recontamination from upstream sources is high, metals were not considered to be primary remediation footprint drivers. Nevertheless, areas of elevated metals concentrations were addressed indirectly by developing a footprint to remediate the primary constituents that exhibit clear patterns of elevated concentrations: bulk sediment pH and phenol.

Summary

Application of the decision tree to the target analytes for the Site suggests that the majority of constituents are neither elevated above background conditions nor associated with variance in benthic toxicity and benthic community metrics. Key findings regarding the primary project footprint drivers are noted below:

- Two constituents represent the key project drivers: bulk sediment pH and phenol. Figures A-4 and A-5 show the spatial distribution (using IDW interpolations) of surface samples for each constituent. The IM addresses all but one exceedance of the BSL for both bulk sediment pH and phenol. When areas with phenol concentrations greater than 1.25 mg/kg are remediated, hypothesis testing shows that their remaining distribution is the same as upstream locations.

- Total PAH and toluene exhibit elevated concentrations in Site sediments, weak-to-moderate associations with benthic community impairment or toxicity, and a similar spatial footprint to the key drivers. The IM addresses the majority of exceedances of the BSL for total PAH and the single exceedance for toluene.

- Metals exhibit strong correlations with one another across most Site locations and depth intervals, and spatial patterns suggest that concentrations are generally elevated in areas of greater sediment deposition (i.e., greater sediment thickness and higher percentage of fines) (Figure A-3). The IM addresses areas of elevated metals concentrations for most of the metals, and the few samples with remaining exceedances (e.g., beryllium, mercury, thallium) are all within a factor of two of the respective BSLs.

- Total cyanide is not a footprint driver despite exhibiting elevated concentrations in Site sediment because geochemical conditions favor iron-cyanide complexes, which are very stable and have low bioavailability (Appendix B). In addition, the association with Site-specific benthic community metrics and toxicity testing is weak. The IM developed from other key constituents can be expected to reduce the areas of elevated cyanide so that the likelihood of an exceedance of the BSL is comparable to Upstream conditions (Figure A-6 and Table A-16).

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Tables

Table A-1 - Summary of Exceedance of Upstream BSLs by Surface and Core Maximum Site Data

Group	Analyte	BSL			Surface Exceedances All Data		Core Maximum Exceedances All Data		Surface Exceedances Outside Footprint		Core Maximum Exceedances Outside Footprint		Potential Footprint Driver
		Dataset	Value (µg/kg)	Value (mg/kg)	Count / N	Percent	Count / N	Percent	Count / N	Percent	Count / N	Percent	
Metal	Aluminum	Full Dataset	12400000	12,400	1 / 56	1.8%	1 / 56	1.8%	-- / 19	0.0%	-- / 19	0.0%	X
	Antimony	Full Dataset	6120	6.1	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Arsenic	Full Dataset	22400	22	3 / 56	5.4%	7 / 56	12.5%	-- / 19	0.0%	1 / 19	5.3%	X
	Barium	Full Dataset	264000	264	-- / 56	0.0%	3 / 56	5.4%	-- / 19	0.0%	1 / 19	5.3%	X
	Beryllium	Full Dataset	830	0.83	11 / 56	19.6%	18 / 56	32.1%	1 / 19	5.3%	2 / 19	10.5%	X
	Cadmium	Full Dataset	24600	25	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Chromium	Full Dataset	446000	446	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Cobalt	Full Dataset	12900	13	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Copper	Full Dataset	487000	487	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Lead	Full Dataset	538000	538	1 / 56	1.8%	7 / 56	12.5%	-- / 19	0.0%	1 / 19	5.3%	X
	Mercury	Full Dataset	3480	3.5	1 / 56	1.8%	1 / 56	1.8%	1 / 19	5.3%	1 / 19	5.3%	X
	Nickel	Full Dataset	261000	261	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Selenium	Full Dataset	2100	2.1	1 / 56	1.8%	7 / 56	12.5%	-- / 19	0.0%	2 / 19	10.5%	X
	Silver	Full Dataset	6890	6.9	1 / 56	1.8%	1 / 56	1.8%	1 / 19	5.3%	1 / 19	5.3%	X
	Thallium	Full Dataset	500	0.50	17 / 56	30.4%	25 / 56	44.6%	6 / 19	31.6%	8 / 19	42.1%	X
	Vanadium	Full Dataset	42300	42	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
	Zinc	Full Dataset	966000	966	-- / 56	0.0%	-- / 56	0.0%	-- / 19	0.0%	-- / 19	0.0%	
Miscellaneous	Sulfide	Full Dataset	1540000	1,540	-- / 57	0.0%	1 / 57	1.8%	-- / 19	0.0%	-- / 19	0.0%	X
	Sulfide	Excluding Outlier(s)	565000	565	4 / 57	7.0%	7 / 57	12.3%	-- / 19	0.0%	1 / 19	5.3%	X
	Bulk Sediment pH	Full Dataset		10.3 (s.u.)	16 / 104	15.4%	51 / 104	49.0%	1 / 21	4.8%	4 / 21	19.0%	X
	Total Cyanide	Full Dataset	5750	5.8	19 / 56	33.9%	36 / 56	64.3%	2 / 19	10.5%	8 / 19	42.1%	X
	Total Organic Carbon	Full Dataset	169000000	169,000	2 / 63	3.2%	2 / 63	3.2%	-- / 21	0.0%	-- / 21	0.0%	X
Pesticides and PCBs	4,4'-DDE	Full Dataset	584	0.58	-- / 29	0.0%	-- / 29	0.0%	-- / 6	0.0%	-- / 6	0.0%	
	Aroclor-1248	Full Dataset	13800	14	-- / 29	0.0%	-- / 29	0.0%	-- / 6	0.0%	-- / 6	0.0%	
	Aroclor-1254	Full Dataset	5810	5.8	-- / 29	0.0%	1 / 29	3.4%	-- / 6	0.0%	-- / 6	0.0%	X
	Aroclor-1260	Full Dataset	1810	1.8	1 / 29	3.4%	2 / 29	6.9%	1 / 6	16.7%	1 / 6	16.7%	X
SVOC	2,4,6-Trichlorophenol	Full Dataset	840	0.84	39 / 56	69.6%	47 / 56	83.9%	12 / 19	63.2%	13 / 19	68.4%	X
	2,4-Dimethylphenol	Full Dataset	420	0.42	36 / 56	64.3%	52 / 56	92.9%	13 / 19	68.4%	17 / 19	89.5%	X
	2,4-Dinitrotoluene	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	2-Chlorophenol	Full Dataset	220	0.22	56 / 56	100.0%	56 / 56	100.0%	19 / 19	100.0%	19 / 19	100.0%	X
	2-Methylnaphthalene	Full Dataset	23000	23	-- / 56	0.0%	1 / 56	1.8%	-- / 19	0.0%	1 / 19	5.3%	X
	3-Methylphenol & 4-Methylphenol	Full Dataset	1400	1.4	9 / 56	16.1%	27 / 56	48.2%	3 / 19	15.8%	8 / 19	42.1%	X
	4-Chloro-3-Methylphenol	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Acenaphthylene	Full Dataset	4360	4.4	10 / 56	17.9%	22 / 56	39.3%	2 / 19	10.5%	9 / 19	47.4%	X
	Anthracene	Full Dataset	20100	20	10 / 56	17.9%	21 / 56	37.5%	2 / 19	10.5%	8 / 19	42.1%	X
	Benzo(a)anthracene	Full Dataset	15300	15	14 / 56	25.0%	31 / 56	55.4%	5 / 19	26.3%	14 / 19	73.7%	X
	Benzo(a)pyrene	Full Dataset	13700	14	12 / 56	21.4%	28 / 56	50.0%	3 / 19	15.8%	11 / 19	57.9%	X
	Benzo(b)fluoranthene	Full Dataset	18000	18	11 / 56	19.6%	26 / 56	46.4%	2 / 19	10.5%	11 / 19	57.9%	X
	Benzo(b)fluoranthene	Excluding Outlier(s)	16300	16	13 / 57	22.8%	27 / 57	47.4%	3 / 19	15.8%	12 / 19	63.2%	X
	Benzo(g,h,i)perylene	Full Dataset	7770	7.8	11 / 56	19.6%	27 / 56	48.2%	2 / 19	10.5%	11 / 19	57.9%	X
	Benzo(k)fluoranthene	Full Dataset	3240	3.2	11 / 56	19.6%	22 / 56	39.3%	5 / 19	26.3%	9 / 19	47.4%	X
	Benzyl Alcohol	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Bis(2-ethylhexyl)phthalate	Full Dataset	19200	19	2 / 56	3.6%	4 / 56	7.1%	1 / 19	5.3%	2 / 19	10.5%	X
	Chrysene	Full Dataset	21000	21	10 / 56	17.9%	23 / 56	41.1%	2 / 19	10.5%	9 / 19	47.4%	X
	Dibenzofuran	Full Dataset	1830	1.8	17 / 56	30.4%	34 / 56	60.7%	8 / 19	42.1%	14 / 19	73.7%	X
	Di-n-Octylphthalate	Full Dataset	1440	1.4	34 / 56	60.7%	43 / 56	76.8%	13 / 19	68.4%	14 / 19	73.7%	X
	Fluoranthene	Full Dataset	26900	27	17 / 56	30.4%	34 / 56	60.7%	6 / 19	31.6%	13 / 19	68.4%	X
	Fluorene	Full Dataset	12400	12	9 / 56	16.1%	18 / 56	32.1%	1 / 19	5.3%	7 / 19	36.8%	X
	Indene	Full Dataset	452	0.45	9 / 56	16.1%	16 / 56	28.6%	1 / 19	5.3%	5 / 19	26.3%	X
	Indeno(1,2,3-cd)pyrene	Full Dataset	5920	5.9	13 / 56	23.2%	30 / 56	53.6%	4 / 19	21.1%	13 / 19	68.4%	X
	Naphthalene	Full Dataset	8290	8.3	5 / 56	8.9%	9 / 56	16.1%	1 / 19	5.3%	3 / 19	15.8%	X
	N-Nitroso-di-n-propylamine	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Pentachlorophenol	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Phenanthrene	Full Dataset	65000	65	10 / 56	17.9%	17 / 56	30.4%	2 / 19	10.5%	6 / 19	31.6%	X
	Phenol	Full Dataset	275	0.28	31 / 56	55.4%	42 / 56	75.0%	8 / 19	42.1%	10 / 19	52.6%	X
	Pyrene	Full Dataset	30600	31	12 / 56	21.4%	26 / 56	46.4%	3 / 19	15.8%	10 / 19	52.6%	X
	Pyrene	Excluding Outlier(s)	210	0.21	56 / 57	98.2%	56 / 57	98.2%	19 / 19	100.0%	19 / 19	100.0%	X
Total PAHs	Total PAHs	Full Dataset	176000	176	13 / 56	23.2%	31 / 56	55.4%	4 / 19	21.1%	13 / 19	68.4%	X
VOC	1,2,4-Trichlorobenzene	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	1,2-Dichlorobenzene	Full Dataset	106	0.11	52 / 56	92.9%	55 / 56	98.2%	16 / 19	84.2%	19 / 19	100.0%	X
	1,2-Dichloropropane	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	1,3-Dichlorobenzene	Full Dataset	23	0.02	28 / 29	96.6%	28 / 29	96.6%	6 / 6	100.0%	6 / 6	100.0%	X
	1,4-Dichlorobenzene	Full Dataset	25	0.03	23 / 29	79.3%	27 / 29	93.1%	4 / 6	66.7%	5 / 6	83.3%	X
	2-Butanone	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Benzene	Full Dataset	72.1	0.07	14 / 56	25.0%	29 / 56	51.8%	1 / 19	5.3%	6 / 19	31.6%	X
	Chlorobenzene	Full Dataset	--	--	-- / 56	--	-- / 56	--	-- / 19	--	-- / 19	--	
	Ethylbenzene	Full Dataset	120	0.12	1 / 56	1.8%	4 / 56	7.1%	-- / 19	0.0%	1 / 19	5.3%	X
	Ethylbenzene	Excluding Outlier(s)	91.7	0.09	8 / 56	14.3%	19 / 56	33.9%	1 / 19	5.3%	5 / 19	26.3%	X
	Isopropylbenzene	Full Dataset	60	0.06	27 / 56	48.2%	43 / 56	76.8%	6 / 19	31.6%	12 / 19	63.2%	X
	Isopropylbenzene	Excluding Outlier(s)	48.2	0.05	29 / 56	51.8%	45 / 56	80.4%	7 / 19	36.8%	13 / 19	68.4%	X
	sec-Butylbenzene	Full Dataset	85.5	0.09	32 / 56	57.1%	41 / 56	73.2%	8 / 19	42.1%	12 / 19	63.2%	X
	Styrene	Full Dataset	74.7	0.07	30 / 56	53.6%	37 / 56	66.1%	7 / 19	36.8%	10 / 19	52.6%	X
	Toluene	Full Dataset	326	0.33	1 / 56	1.8%	3 / 56	5.4%	-- / 19	0.0%	2 / 19	10.5%	X
	Xylenes (total)	Full Dataset	284	0.28	7 / 56	12.5%	14 / 56	25.0%	1 / 19	5.3%	2 / 19	10.5%	X
	Xylenes (total)	Excluding Outlier(s	270	0.27	7 / 56	12.5%	14 / 56	25.0%	1 / 19	5.3%	2 / 19	10.5%	X

Notes:
BSL = Background Screening Level
N = total sample size (detects and nondetects)
mg/kg = milligrams per kilogram
-- = no detects to screen against BSL
SVOC = semi-volatile organic compound
VOC = volatile organic compound
PAHs = polyaromatic hydrocarbon

Table A-2 - Hypothesis Test Results for All Depths

Group	Analyte[1]	Dataset[2]	Along Site Dataset				Upstream Dataset				Upper Tail (Quantile Test)			Central Tendency Test			
			# Detects	N	FOD %	Distribution[3]	# Detects	N	FOD %	Distribution[3]	K	# Site in R	Evidence of Impact?[4,5]	Test[6]	Test Value	Critical Value	Evidence of Impact?[7,8]
Metals	Aluminum	full dataset	130	130	100%	N	69	69	100%	N	8	9	yes	t-Test	-1.442	1.654	no
	Antimony	full dataset	130	130	100%	G	69	69	100%	G	8	0	no	WMW	-5.449	1.645	no
	Arsenic	full dataset	130	130	100%	Ln	69	69	100%	NP	8	9	yes	WMW	-2.704	1.645	no
	Barium	full dataset	130	130	100%	N	69	69	100%	NP	8	3	no	WMW	-5.436	1.645	no
	Beryllium	full dataset	130	130	100%	N	69	69	100%	NP	8	11	yes	WMW	1.875	1.645	yes
	Cadmium	full dataset	130	130	100%	NP	69	69	100%	N	8	4	no	WMW	-4.997	1.645	no
	Chromium	full dataset	130	130	100%	NP	69	69	100%	NP	8	2	no	WMW	-5.826	1.645	no
	Cobalt	full dataset	130	130	100%	G	69	69	100%	NP	8	1	no	WMW	-6.885	1.645	no
	Copper	full dataset	130	130	100%	NP	69	69	100%	N	8	0	no	WMW	-7.173	1.645	no
	Lead	full dataset	130	130	100%	NP	69	69	100%	N	8	9	yes	WMW	-4.724	1.645	no
	Mercury	full dataset	130	130	100%	G	69	69	100%	G	8	5	no	WMW	-2.542	1.645	no
	Nickel	full dataset	130	130	100%	Ln	69	69	100%	N/G/Ln	8	5	no	WMW	-5.621	1.645	no
	Selenium	full dataset	130	130	100%	NP	69	69	100%	NP	8	9	yes	WMW	-2.88	1.645	no
	Silver	full dataset	130	130	100%	G	67	69	97%	N	8	5	no	Gehan	-5.6	1.645	no
	Thallium	full dataset	130	130	100%	G	69	69	100%	NP	8	9	yes	WMW	-0.123	1.645	no
	Vanadium	full dataset	130	130	100%	N/G	69	69	100%	N	8	0	no	t-Test	-7.251	1.66	no
	Zinc	full dataset	130	130	100%	NP	69	69	100%	NP	8	0	no	WMW	-7.557	1.645	no
Miscellaneous	Field pH	full dataset	130	130	100%	NP	69	69	100%	N/G/Ln	8	9	yes	WMW	9.038	1.645	yes
	Sulfide	full dataset	125	130	96%	NP	69	69	100%	NP	8	4	no	Gehan	-0.331	1.645	no
	Total Cyanide	full dataset	111	130	85%	NP	68	69	99%	NP	8	9	yes	Gehan	3.658	1.645	yes
	Total Organic Carbon	full dataset	130	130	100%	NP	69	69	100%	N	8	1	no	WMW	-4.653	1.645	no
Pesticides and PCBs	4,4-DDE	full dataset	87	130	67%	NP	49	69	71%	Ln	8	1	no	Gehan	-3.038	1.645	no
	Aroclor 1248	full dataset	75	130	58%	NP	53	69	77%	NP	8	1	no	Gehan	-3.704	1.645	no
	Aroclor 1254	full dataset	87	130	67%	NP	54	69	78%	NP	8	2	no	Gehan	-3.762	1.645	no
	Aroclor 1260	full dataset	91	130	70%	NP	56	69	81%	NP	8	6	no	Gehan	-3.945	1.645	no
	Total PCBs	full dataset	94	130	72%	Ln	57	69	83%	G	8	2	no	WMW	-3.321	1.645	no
SVOCs	2,4,6-Trichlorophenol	full dataset	0	130	0%	NA	1	69	1%	NA	NA	NA	NA	NA	NA	NA	NA
	2,4-Dimethylphenol	full dataset	24	130	18%	NP	4	69	6%	NA	NA	NA	NA	NA	NA	NA	NA
	2,4-Dinitrotoluene	full dataset	0	130	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	2-Chlorophenol	full dataset	0	130	0%	NA	1	69	1%	NA	NA	NA	NA	NA	NA	NA	NA
	2-Methylnaphthalene	full dataset	128	130	98%	NP	65	69	94%	Ln	8	2	no	Gehan	-2.365	1.645	no
	3-Methylphenol & 4-Methylphenol[9]	full dataset	115	130	88%	Ln	54	69	78%	G	8	10	yes	Gehan	0.71	1.645	no
	4-Chloro-3-methylphenol	full dataset	0	130	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	Acenaphthylene	full dataset	120	130	92%	Ln	65	69	94%	Ln	8	6	no	Gehan	-1.609	1.645	no
	Anthracene	full dataset	127	130	98%	Ln	68	69	99%	Ln	8	7	no	Gehan	0.453	1.645	no
	Benzo(a)anthracene	full dataset	129	130	99%	NP	68	69	99%	NP	8	8	yes	WMW	-1.146	1.645	no
	Benzo(a)pyrene	full dataset	128	130	98%	NP	68	69	99%	NP	8	8	yes	WMW	-1.615	1.645	no
	Benzo(b)fluoranthene	full dataset	128	130	98%	NP	68	69	99%	N	8	9	yes	Gehan	-1.197	1.645	no
	Benzo(ghi)perylene	full dataset	128	130	98%	NP	68	69	99%	NP	8	8	yes	WMW	-1.65	1.645	no
	Benzo(k)fluoranthene[9]	full dataset	12	130	9%	NP	13	69	19%	NP	8	4	no	Gehan	-2.134	1.645	no
	Benzyl Alcohol	full dataset	0	130	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	bis(2-Chloroisopropyl)ether	full dataset	6	130	5%	NP	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	bis(2-Ethylhexyl)phthalate	full dataset	80	130	62%	NP	47	69	68%	G	8	5	no	Gehan	-4.18	1.645	no
	Chrysene	full dataset	129	130	99%	NP	68	69	99%	NP	8	7	no	WMW	-1.699	1.645	no
	Dibenzofuran[9]	full dataset	121	130	93%	Ln	59	69	86%	G	8	8	yes	Gehan	1.029	1.645	no
	Di-n-octyl Phthalate[9]	full dataset	14	130	11%	NP	15	69	22%	Ln	8	7	no	Gehan	0.0833	1.645	no
	Fluoranthene	full dataset	129	130	99%	NP	68	69	99%	NP	8	9	yes	WMW	-0.802	1.645	no
	Fluorene	full dataset	127	130	98%	Ln	63	69	91%	NP	8	5	no	Gehan	0.649	1.645	no
	Indene[9]	full dataset	75	130	58%	Ln	44	69	64%	Ln	8	4	no	Gehan	-3.407	1.645	no
	Indeno(1,2,3-cd)pyrene	full dataset	128	130	98%	NP	68	69	99%	NP	8	8	yes	WMW	-0.971	1.645	no
	Naphthalene	full dataset	128	130	98%	NP	66	69	96%	NP	8	6	no	Gehan	-1.014	1.645	no
	n-Nitrosodi-n-propylamine	full dataset	0	130	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	Pentachlorophenol	full dataset	0	130	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	Phenanthrene	full dataset	130	130	100%	Ln	68	69	99%	NP	8	7	no	WMW	-0.182	1.645	no

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Table A-2 - Hypothesis Test Results for All Depths

Group	Analyte[1]	Dataset[2]	Along Site Dataset				Upstream Dataset				Upper Tail (Quantile Test)			Central Tendency Test			
			# Detects	N	FOD %	Distribution[3]	# Detects	N	FOD %	Distribution[3]	K	# Site in R	Evidence of Impact?[4,5]	Test[6]	Test Value	Critical Value	Evidence of Impact?[7,8]
SVOCs	Phenol[9]	full dataset	84	130	65%	Ln	7	69	10%	NP	8	9	yes	Gehan	6.533	1.645	yes
(cont.)	Pyrene	full dataset	129	130	99%	NP	68	69	99%	NP	8	7	no	WMW	-1.275	1.645	no
VOCs	1,2,4-Trichlorobenzene	full dataset	0	119	0%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	1,2-Dichlorobenzene	full dataset	2	119	2%	NA	5	69	7%	N/Ln	NA	NA	NA	NA	NA	NA	NA
	1,2-Dichloropropane	full dataset	4	119	3%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	1,3-Dichlorobenzene	full dataset	0	119	0%	NA	1	69	1%	NA	NA	NA	NA	NA	NA	NA	NA
	1,4-Dichlorobenzene	full dataset	17	119	14%	NP	1	69	1%	NA	NA	NA	NA	NA	NA	NA	NA
	2-Butanone	full dataset	1	119	1%	NA	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	Benzene[9]	full dataset	64	124	52%	NP	51	69	74%	NP	8	6	no	Gehan	0.0526	1.645	no
	Chlorobenzene	full dataset	19	119	16%	NP	0	69	0%	NA	NA	NA	NA	NA	NA	NA	NA
	Ethylbenzene[9]	full dataset	46	126	37%	NP	32	69	46%	NP	8	0	no	Gehan	-3.009	1.645	no
	Isopropylbenzene[9]	full dataset	61	128	48%	NP	46	69	67%	NP	8	6	no	Gehan	1.027	1.645	no
	sec-Butylbenzene[9]	full dataset	24	123	20%	NP	11	69	16%	NP	9	8	no	Gehan	1.221	1.645	no
	Styrene[9]	full dataset	8	120	7%	NP	10	69	14%	NP	8	2	no	Gehan	-2.61	1.645	no
	Toluene[9]	full dataset	104	129	81%	G/Ln	63	69	91%	NP	8	7	no	Gehan	1.283	1.645	no
	Xylenes[9]	full dataset	78	127	61%	Ln	60	69	87%	N	8	3	no	Gehan	-2.968	1.645	no
Total PAH	Total PAH	full dataset	130	130	100%	NP	69	69	100%	NP	8	7	no	WMW	-0.918	1.645	no

Abbreviations:

FOD % = frequency of detection = (Detects / N) x 100%
Ho = null hypothesis
N = sample size
NA = nondetect values in the "R" largest site observations; cannot complete Quantile Test and maintain sufficient sample size
K = critical value to compare with number of site observations among "R "largest site observations
R = number of largest values to examine in the upper tail of the distribution combining background and site datasets
WMW = Wilcoxon-Mann-Whitney

Notes:

[1] Hypothesis testing not conducted for analytes with less then 8 total observations or less than 5 detected observations (USEPA 2007).
[2] Results are reported for full datasets only; outliers were identified, but all are plausible (within approximately one order of magnitude of maximum detect excluding outliers).
[3] Distribution assessed by goodness-of-fit tests based on detected values only conducted using ProUCL 4.0 at a 95% confidence level (α = 0.05).
Distributions:
Normal (N): data set follows a normal distribution, according to the Shapiro-Wilk test.
Gamma (G): data set follows a gamma distribution, according to the Kolmogorov-Smirnov test.
Lognormal (Ln): data set follows a lognormal distribution, according to the Shapiro-Wilk test.
Nonparametric (NP): data set does not follow any of the three distributions noted above.
[4] Null hypothesis Ho: Site concentrations≤ Background concentrations (Form 1).
[5] Reject Ho if the number of site observations in the "R" largest values≥ K. Conclusions are based on α = 0.05.
[6] Appropriate hypothesis test selected based on degree of censoring, and range of nondetect, and distribution of the data set:
t-Test: FOD = 100%, normal
WMW test: 40% < FOD ≤ 100%, data set includes nondetects with a single reporting limit, normal/lognormal/nonparametric
Gehan test: FOD < 100%, data set includes nondetects with multiple (different) reporting limits, normal/lognormal/nonparametric
[7] Null hypothesis Ho: Site Mean/Median≤ Background Mean/Median (Form 1).
[8] Reject Ho if test statistic is greater than the critical value. Conclusions are based on α = 0.05.
[9] Nondetect values were present in the "R" largest observations of the site dataset. Nondetects in the "R" largest observations were ignored (e.g., set to the minimum detected concentration to maintain sample size).

References:

Guenther, W.C. 1972. Tolerance Intervals for Univariate Distributions. Naval Research Logistics Quarterly. 19:309-333.
USEPA. 2007. ProUCL Version 4.0 Technical Guide. Office of Research and Development. EPA/600/R-07/041. April.

Table A-3 - Hypothesis Test Results for Surface Sediment (0 to 1 ft)

Group	Analyte[1]	Depth Interval	Along Site Dataset				Upstream Dataset				Upper Tail (Quantile Test)			Central Tendency Test			
			# Detects	N	FOD %	Distribution[3]	# Detects	N	FOD %	Distribution[3]	K	# Site in R	Evidence of Impact?[4,5]	Test[6]	Test Value	Critical Value	Evidence of Impact?[7,8]
Metals	Aluminum	Surface	56	56	100%	N/G	18	18	100%	N	9	8	no	WMW	-0.202	-1.645	yes
	Antimony	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	7	no	WMW	-1.877	-1.645	no
	Arsenic	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	8	no	WMW	-0.283	-1.645	yes
	Barium	Surface	56	56	100%	N/G	18	18	100%	N/G	9	6	no	WMW	-2.243	-1.645	no
	Beryllium	Surface	56	56	100%	N/G	18	18	100%	N/G	9	9	yes	WMW	1.524	-1.645	yes
	Cadmium	Surface	56	56	100%	Ln	18	18	100%	N/G/Ln	9	6	no	WMW	-2.079	-1.645	no
	Chromium	Surface	56	56	100%	Ln	18	18	100%	N/G/Ln	9	4	no	WMW	-3.131	-1.645	no
	Cobalt	Surface	56	56	100%	N/G/Ln	18	18	100%	N/G	9	5	no	WMW	-3.131	-1.645	no
	Copper	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	2	no	WMW	-3.584	-1.645	no
	Lead	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	6	no	WMW	-2.331	-1.645	no
	Mercury	Surface	56	56	100%	G	18	18	100%	G/Ln	9	6	no	WMW	0.22	-1.645	yes
	Nickel	Surface	56	56	100%	Ln	18	18	100%	N/G/Ln	9	3	no	WMW	-2.721	-1.645	no
	Selenium	Surface	52	55	95%	G/Ln	18	18	100%	N/G	9	6	no	Gehan	-2.642	-1.645	no
	Silver	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	5	no	WMW	-2.501	-1.645	no
	Thallium	Surface	56	56	100%	G/Ln	18	18	100%	N	9	9	yes	WMW	1.083	-1.645	yes
	Vanadium	Surface	56	56	100%	N	18	18	100%	N/G	9	1	no	WMW	-3.71	-1.645	no
	Zinc	Surface	56	56	100%	G/Ln	18	18	100%	N/G	9	4	no	WMW	-3.994	-1.645	no
Miscellaneous	Field pH	Surface	58	58	100%	N/G/Ln	18	18	100%	N/G/Ln	10	10	yes	WMW	5.626	-1.645	yes
	Percent Solids	Surface	58	58	100%	N/G/Ln	18	18	100%	Ln	10	7	no	WMW	0.318	-1.645	yes
	Sulfide	Surface	52	53	98%	G	18	18	100%	G/Ln	9	5	no	WMW	N/A	-1.645	yes
	Total Cyanide	Surface	55	56	98%	Ln	17	18	94%	G/Ln	9	9	yes	WMW	2.791	-1.645	yes
	Total Organic Carbon	Surface	53	53	100%	NP	18	18	100%	N/G	9	5	no	WMW	-1.897	-1.645	no
Pesticides	4,4-DDE	Surface	27	29	93%	Ln	16	18	89%	Ln	8	2	no	Gehan	-1.577	-1.645	yes
	Aroclor 1248	Surface	25	29	86%	N/Ln	17	18	94%	Ln	8	2	no	Gehan	-2.279	-1.645	no
	Aroclor 1254	Surface	25	29	86%	N/Ln	16	18	89%	Ln	8	2	no	Gehan	-2.498	-1.645	no
	Aroclor 1260	Surface	28	29	97%	Ln	17	18	94%	Ln	8	2	no	WMW	-2.451	-1.645	no
SVOCs	2-Methylnaphthalene	Surface	56	56	100%	Ln	16	18	89%	Ln	9	8	no	Gehan	1.306	-1.645	yes
	3-Methylphenol & 4-Methylphenol[8]	Surface	50	56	89%	G/Ln	11	18	61%	G/Ln	15	13	no	Gehan	-0.57	-1.645	yes
	Acenaphthylene	Surface	54	56	96%	Ln	16	18	89%	Ln	9	9	yes	Gehan	1.436	-1.645	yes
	Anthracene	Surface	56	56	100%	Ln	18	18	100%	G/Ln	9	9	yes	WMW	3.011	-1.645	yes
	Benzo(a)anthracene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.745	-1.645	yes
	Benzo(a)pyrene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.304	-1.645	yes
	Benzo(b)fluoranthene	Surface	56	56	100%	Ln	18	18	100%	N/G	9	9	yes	WMW	1.216	-1.645	yes
	Benzo(ghi)perylene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	0.895	-1.645	yes
	bis(2-Ethylhexyl)phthalate[9]	Surface	36	56	64%	Ln	17	18	94%	N/Ln	9	5	no	Gehan	-4.315	-1.645	no
	Chrysene	Surface	56	56	100%	Ln	18	18	100%	N/G	9	9	yes	WMW	1.298	-1.645	yes
	Dibenzofuran	Surface	55	56	98%	Ln	13	18	72%	G/Ln	9	10	yes	Gehan	2.555	-1.645	yes
	Di-n-octyl Phthalate[9]	Surface	8	56	14%	NP	6	18	33%	G/Ln	1	0	no	Gehan	-0.913	-1.645	yes
	Fluoranthene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.94	-1.645	yes
	Fluorene	Surface	56	56	100%	Ln	14	18	78%	Ln	9	9	yes	Gehan	3.429	-1.645	yes
	Indene[9]	Surface	41	56	73%	G/Ln	10	18	56%	G	14	12	no	Gehan	1.21	-1.645	yes
	Indeno(1,2,3-cd)pyrene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.373	-1.645	yes
	Naphthalene	Surface	56	56	100%	Ln	17	18	94%	G	9	9	yes	WMW	2.684	-1.645	yes
	Phenanthrene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	2.614	-1.645	yes
	Pyrene	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.569	-1.645	yes
VOCs	Benzene[9]	Surface	38	55	69%	G	10	18	56%	NP	13	11	no	Gehan	0.147	-1.645	yes
	Isopropylbenzene[9]	Surface	30	56	54%	NP	10	18	56%	G/Ln	9	8	no	Gehan	1.744	-1.645	yes
	Toluene[9]	Surface	50	56	89%	G/Ln	15	18	83%	G/Ln	12	9	no	Gehan	0.769	-1.645	yes
	Total PAHs	Surface	56	56	100%	Ln	18	18	100%	G	9	9	yes	WMW	1.808	-1.645	yes
	Xylenes[9]	Surface	41	56	73%	NP	15	18	83%	G/Ln	9	7	no	Gehan	1.348	-1.645	yes

Table A-3 - Hypothesis Test Results for Surface Sediment (0 to 1 ft)

Abbreviations:

FOD % = frequency of detection = (Detects / N) x 100%
Ho = null hypothesis
N = sample size
NA = nondetect values in the "R" largest site observations; cannot complete Quantile Test and maintain sufficient sample size
K = critical value to compare with number of site observations among "R "largest site observations
R = number of largest values to examine in the upper tail of the distribution combining background and site datasets
WMW = Wilcoxon-Mann-Whitney

Notes:

1 Hypothesis testing not conducted for analytes with less then 8 total observations or less than 5 detected observations (USEPA, 2007).
2 Results are reported for full datasets only; outliers were identified, but all are plausible (within approximately one order of magnitude of maximum detect excluding outliers).
3 Distribution assessed by goodness-of-fit tests based on detected values only conducted using ProUCL 4.0 at a 95% confidence level (α = 0.05).
Distributions:
Normal (N): data set follows a normal distribution, according to the Shapiro-Wilk test.
Gamma (G): data set follows a gamma distribution, according to the Kolmogorov-Smirnov test.
Lognormal (Ln): data set follows a lognormal distribution, according to the Shapiro-Wilk test.
Nonparametric (NP): data set does not follow any of the three distributions noted above.
4 Null hypothesis Ho: Site concentrations ≤ Background concentrations (Form 1).
5 Reject Ho if the number of site observations in the "R" largest values ≥ K. Conclusions are based on α = 0.05.
6 Appropriate hypothesis test selected based on degree of censoring, and range of nondetect, and distribution of the data set:
t-Test: FOD = 100%, normal
WMW test: 40% < FOD ≤ 100%, data set includes nondetects with a single reporting limit, normal/lognormal/nonparametric
Gehan test: FOD < 100%, data set includes nondetects with multiple (different) reporting limits, normal/lognormal/nonparametric
7 Null hypothesis Ho: Site Mean/Median ≤ Background Mean/Median (Form 1).
8 Reject Ho if test statistic is greater than the critical value. Conclusions are based on α = 0.05.
9 Nondetect values were present in the "R" largest observations of the site dataset. Nondetects in the "R" largest observations were ignored (e.g., set to the minimum detected concentration to maintain sample size).

References:

Guenther, W.C. 1972. Tolerance Intervals for Univariate Distributions. Naval Research Logistics Quarterly. 19:309-333.
USEPA. 2007. ProUCL Version 4.0 Technical Guide. Office of Research and Development. EPA/600/R-07/041. April.

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Table A-4 - Spearman Rank Correlation for Chemistry Variables

Metals

Excluded		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Vanadium	Zinc
	Aluminum	1																
	Antimony	0.64	1															
	Arsenic	0.62	0.79	1														
X	Barium	0.76	0.87	0.71	1													
	Beryllium	0.79	0.48	0.46	0.59	1												
X	Cadmium	0.67	0.94	0.74	0.88	0.49	1											
	Chromium	0.59	0.87	0.65	0.88	0.43	0.93	1										
X	Cobalt	0.69	0.81	0.74	0.82	0.39	0.81	0.82	1									
	Copper	0.71	0.85	0.73	0.85	0.46	0.88	0.81	0.84	1								
	Lead	0.64	0.82	0.74	0.85	0.41	0.82	0.79	0.77	0.84	1							
	Mercury	0.71	0.72	0.67	0.73	0.53	0.73	0.59	0.65	0.84	0.76	1						
X	Nickel	0.56	0.83	0.64	0.84	0.40	0.88	0.97	0.84	0.79	0.75	0.54	1					
	Selenium	0.62	0.64	0.59	0.71	0.45	0.68	0.65	0.64	0.65	0.58	0.49	0.64	1				
X	Silver	0.66	0.84	0.62	0.86	0.41	0.89	0.93	0.84	0.86	0.79	0.67	0.89	0.67	1			
	Thallium	0.72	0.80	0.82	0.76	0.59	0.79	0.68	0.74	0.76	0.76	0.79	0.65	0.56	0.69	1		
	Vanadium	0.74	0.57	0.58	0.67	0.53	0.57	0.53	0.68	0.67	0.57	0.52	0.51	0.63	0.56	0.51	1	
	Zinc	0.66	0.88	0.72	0.87	0.37	0.91	0.87	0.87	0.94	0.89	0.76	0.85	0.64	0.89	0.73	0.62	1
	Cyanide	0.17	-0.13	-0.04	-0.03	0.30	-0.13	-0.18	-0.21	-0.09	-0.15	-0.02	-0.19	0.11	-0.14	-0.02	0.10	-0.21

PCBs and Pesticides

		PCB1248	PCB1254	PCB1260	4,4 DDE
X	PCB1248	1			
X	PCB1254	0.95	1		
	PCB1260	0.95	0.96	1	
	4,4 DDE	0.96	0.96	0.937	1

Volatile Organic Compounds

		TCBENZ	DCBENZ	Benzene	CHLBENZ	ETHBENZ	ISOBENZ	SECBENZ	STYRENE	TOLUENE	VC	Xylenes
X	TCBENZ	1										
X	DCBENZ	0.93	1									
	Benzene	0.36	0.35	1								
X	CHLBENZ	0.88	0.83	0.42	1							
	ETHBENZ	0.55	0.53	0.37	0.51	1						
	ISOBENZ	0.35	0.38	0.52	0.34	0.40	1					
X	SECBENZ	0.88	0.85	0.36	0.80	0.54	0.38	1				
X	STYRENE	0.96	0.91	0.35	0.84	0.56	0.37	0.87	1			
	TOLUENE	0.15	0.16	0.24	0.10	0.19	0.20	0.16	0.15	1		
	VC	0.05	0.07	-0.04	-0.02	-0.03	0.05	0.03	0.08	-0.01	1	
	Xylenes	0.40	0.37	0.54	0.43	0.42	0.36	0.33	0.38	0.23	0.04	1

Notes:

1. Selected constituents were excluded from subsequent statistical analyses to reduce errors associated with overparameterization. Inferences from subsequent statistical analysis can also be applied to these correlated variables.
2. Correlation coefficient (rho) greater than or equal to 0.7 is highlighted in yellow and bold font.
3. Correlations for all individual PAHs (not shown) were generally very high; Total PAH is used to represent the full set of individual PAHs.

TCBENZ = 1,2,4-TRICHLOROBENZENE
DCBENZ = 1,2-DICHLOROBENZENE
ETHBENZ = ETHYLBENZENE
ISOBENZ = ISOPROPYLBENZENE
VC = VINYL CHLORIDE

Table A-5 - Benthic Organisms Identified from 2009 Site Investigation

Lowest Practical Taxonomic Level			Common Name	Site										Upstream										
High (Typically Order or Class)	→	Low (Typically Genus and Species)		BC-T17-50	BC-T20-175	BC-T22-25	BC-T23-75	BC-T24-75	BC-T25-50	BC-T26-50	BC-T27-50	BC-T28-125	BC-T29-25	BC-U04	BC-U07	BC-U08	BC-U10	BC-U11	BC-U12	BC-U13	BC-U14	BC-U15	BC-U16	BC-U17
Nematoda	Nematoda	Nematoda	Round Worm	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Nemertea	Tetrastemmatidae	Prostoma graecense	Ribbon Worm	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	15	0	0	0
Tricladida	Planariidae	Dugesia tigrina	Flatworm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	0	1
Oligochaeta	Enchytraeidae	Enchytraeidae	Aquatic Worm	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Oligochaeta	Lumbriculidae	Lumbriculus variegatus	Aquatic Worm	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Oligochaeta	Megadril	Aquatic Worm	0	1	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Naidinae	Ophidonais serpentina	Aquatic Worm	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Oligochaeta	Tubificinae	Branchiura sowerbyi	Aquatic Worm	6	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
Oligochaeta	Tubificinae	Ilyodrilus templetoni	Aquatic Worm	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Tubificinae	Immat. tubificid w/hair chaete	Aquatic Worm	0	0	0	0	0	0	0	0	0	0	32	0	0	0	4	0	0	0	0	16	0
Oligochaeta	Tubificinae	Limnodrilus sp.	Aquatic Worm	0	3	0	72	64	152	144	96	0	16	240	128	64	128	36	192	32	0	56	464	56
Oligochaeta	Tubificinae	Limnodrilus claparedeianus	Aquatic Worm	0	0	0	0	0	16	0	96	0	0	0	64	16	64	0	192	0	0	0	224	0
Oligochaeta	Tubificinae	Limnodrilus hoffmeisteri	Aquatic Worm	0	0	0	0	0	0	0	0	0	0	0	0	0	64	16	0	64	0	0	0	0
Oligochaeta	Tubificinae	Quistadrilus multisetosus	Aquatic Worm	3	0	0	0	0	8	0	0	0	0	16	16	16	16	0	32	0	0	0	16	4
Polychaeta	Sabellidae	Manayunkia speciosa	Bristle Worm	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	23	0	0	0
Hirudinea	Erpobdellidae	Mooreobdella microstoma	Leech	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	16	0
Hirudinea	Glossiphoniidae	Alboglossophonia heteroclita	Leech	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Basommatophora	Ancyclidae	Ferrissia rivularis	Limpet Snail	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	44	0	3	0	0	0
Basommatophora	Physidae	Physa sp.	Limpet Snail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Basommatophora	Planorbidae	Helisoma sp.	Limpet Snail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0
Mesogastropoda	Pleuroceridae	Goniobasis livescens	Horn Snail	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Veneroida	Corbiculidae	Corbicula fluminea	Clam/Mussel	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	1	0	16	0
Veneroida	Dreissenidae	Dreissena sp.	Clam/Mussel	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Veneroida	Dreissenidae	Dreissena bugensis	Clam/Mussel	6	3	0	2	0	0	0	0	0	0	0	0	1	0	1	0	0	3	0	0	2
Veneroida	Dreissenidae	Dreissena polymorpha	Clam/Mussel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1
Acariformes	Acariformes	Acariformes	Mite	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	2	0	0	0
Amphipoda	Gammaridae	Gammarus fasciatus	Scud	5	12	0	1	0	0	0	4	8	0	0	0	16	0	0	0	0	21	0	0	4
Amphipoda	Hyalellidae	Hyalella azteca	Scud	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	6	0	3	0	0	0
Ephemeroptera	Caenidae	Caenis sp.	Mayfly	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	Hydropsychidae	Hydropsyche phalerata	Caddisfly	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	2
Trichoptera	Hydroptilidae	Agraylea sp.	Caddisfly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Trichoptera	Hydroptilidae	Hydroptila sp.	Caddisfly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0
Diptera	Chironomidae	Cardiocladius sp.	Midge	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Chironomini	Midge	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	16	0
Diptera	Chironomidae	Chironomus sp.	Midge	0	0	3	1	0	1	0	1	0	0	40	0	32	2	0	0	2	0	0	0	0
Diptera	Chironomidae	Cricotopus sp.	Midge	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Cryptochironomus fulvus gr.	Midge	0	0	0	1	0	0	0	0	0	0	0	0	32	2	1	0	1	0	0	0	8
Diptera	Chironomidae	Demicryptochironomus sp.	Midge	0	0	1	0	0	0	0	3	0	0	0	4	0	2	4	0	2	0	0	0	5
Diptera	Chironomidae	Dicrotendipes sp.	Midge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0
Diptera	Chironomidae	Nanocladius sp.	Midge	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Orthocladius cplx.	Midge	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Parachironomus sp.	Midge	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Paratanytarsus sp.	Midge	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

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Table A-5 - Benthic Organisms Identified from 2009 Site Investigation

Lowest Practical Taxonomic Level				Site										Upstream										
High (Typically Order or Class)	→	Low (Typically Genus and Species)	Common Name	BC-T17-50	BC-T20-175	BC-T22-25	BC-T23-75	BC-T24-75	BC-T25-50	BC-T26-50	BC-T27-50	BC-T28-125	BC-T29-25	BC-U04	BC-U07	BC-U08	BC-U10	BC-U11	BC-U12	BC-U13	BC-U14	BC-U15	BC-U16	BC-U17
Diptera	Chironomidae	Paratendipes sp.	Midge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Diptera	Chironomidae	Phaenopsectra punctipes gr.	Midge	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Polypedilum sp.	Midge	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Procladius sp.	Midge	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Rheotanytarsus sp.	Midge	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Tanypodinae	Midge	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Tanytarsus sp.	Midge	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Thienemanniella sp.	Midge	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Tribelos atrum	Midge	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Diptera	Chironomidae	Tvetenia vitracies	Midge	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes:

1. Benthic community samples were collected from 10 site locations and 11 upstream locations using a box corer sediment sampler (9.65 in x 9.65 in) from the 0-6 inch sample depth.
2. Three replicate samples were collected at each location and composited to form one benthic community sample.
3. Samples were submitted to Normandeau Associates, Inc in Stowe, PA for identification to the lowest practical taxonomic level (typically genus and/or species).

Table A-6 - Benthic Community Metrics by Sampling Location

Sample ID	Total Individuals	Biomass (grams wet weight)	Total Taxa	Percent Oligochaeta	Percent Chironomidae	Percent Insecta	Percent Dominant Taxon	Tolerance Index	Diversity Index	Evenness Index
BC-T17-50	31	5.685	7	29.0	0.0	3.2	19.4	7.42	1.85	0.95
BC-T20-175	36	1.853	14	11.1	16.7	19.4	33.3	6.83	2.20	0.83
BC-T22-25	19	0.02	8	0.0	100	100	47.4	6.68	1.66	0.80
BC-T23-75	109	1.309	6	95.4	1.8	1.8	66.1	8.44	0.84	0.47
BC-T24-75	80	0.12	2	100.0	0.0	0.0	80.0	9.2	0.50	0.72
BC-T25-50	177	0.187	4	99.4	0.6	0.6	85.9	10.0	0.52	0.37
BC-T26-50	144	0.398	1	100	0.0	0.0	100	10.0	0.00	0.00
BC-T27-50	230	0.332	16	90.4	3.9	4.8	41.7	9.67	1.37	0.50
BC-T28-125	16	0.052	2	50.0	0.0	0.0	50.0	5.5	0.69	1.00
BC-T29-25	18	0.041	2	88.9	11.1	11.1	88.9	9.56	0.35	0.50
BC-U04	333	0.676	6	86.5	13.2	13.2	72.1	9.98	0.93	0.52
BC-U07	216	0.314	5	96.3	3.7	3.7	59.3	9.91	1.01	0.63
BC-U08	241	0.387	10	53.1	26.6	26.6	26.6	8.66	2.08	0.90
BC-U10	278	0.775	7	97.8	2.2	2.2	46.0	9.97	1.30	0.67
BC-U11	63	0.286	7	88.9	7.9	7.9	57.1	9.78	1.22	0.63
BC-U12	518	1.464	16	80.3	0.8	3.9	37.1	9.32	1.59	0.58
BC-U13	103	0.14	6	93.2	4.9	4.9	62.1	9.86	0.93	0.52
BC-U14	87	5.15	16	5.8	4.6	5.8	26.4	6.53	2.14	0.77
BC-U15	56	0.032	1	100	0.0	0.0	100	10.0	0.00	0.00
BC-U16	768	0.75	7	93.8	2.1	2.1	60.4	9.79	1.07	0.55
BC-U17	83	3.468	9	72.3	15.7	18.1	67.5	9.16	1.24	0.56
Response[3]	Decrease	Decrease	Decrease	Increase	Increase	Decrease	Increase	Increase	Decrease	Decrease

Table A-6 - Benthic Community Metrics by Sampling Location

Notes:

1. Benthic metrics are used to quantify aspects of community structure and function that change in predictable ways with increased human influence and/or perturbation. They provide a consistent theoretical framework for analyzing complex assemblage data.

2. A total of ten metrics were selected based on acceptable use (those that are widely used), availability in regulatory protocols (MDEQ, USEPA, or Environment Canada), and/or applicability to site conditions (deep water sediment site). These included richness (total individuals, biomass and total taxa), composition (% Oligochaeta, % Chironomidae and % Insecta), tolerance (tolerance index and % dominant taxon), and diversity and evenness measures.

3. Decrease = expect lower value for metric with increasing perturbation; Increase = expect a higher value for metric with increasing perturbation.

Metric Description:

1. Total Individuals: Count of all individuals in the sample. Used as the denominator for several other metrics, and also useful for observing differences in the number of organisms between different samples.

2. Biomass: Measure of wet weight sample mass. Useful for comparing sample differences in biomass and understanding the trophic food base between locations.

3. Total Taxa: Total number of distinct taxa per sample. Measures the overall variety of the species assemblage.

4. Percent Oligochaeta: The relative percent contribution of aquatic worms. A composition metric that provides information on the assemblage and relative contribution to the total fauna.

5. Percent Chironomidae: The relative percent contribution of midge larvae. A composition metric that provides information on the assemblage and relative contribution to the total fauna.

6. Percent Insecta: The relative percent contribution of insect larvae. A composition metric that provides information on the assemblage and relative contribution to the total fauna.

7. Percent Dominant Taxon: The relative percent contribution of the single most dominant benthic taxon. A tolerance metric that provides information on the assemblage and relative contribution to the total fauna (tolerant taxa are often abundant).

8. Tolerance Index: Calculated measure of organism tolerance or sensitivity to perturbation based on abundance and tolerance values ascribed originally by Hilsenhoff (1987). Scores for this index range from 0 to 10 with larger numbers indicating greater tolerance to perturbation.

9. Diversity Index: Measures the diversity of the sample in terms of number of taxa and relative species abundance. Scores for this index typically range from 0 to 4 with larger numbers indicating greater diversity.

10. Evenness Index: Measures the evenness of the sample (how equal the community is numerically) in terms of number of taxa and relative species abundance. Scores for this index range from 0 to 1 with larger numbers indicating greater evenness.

Table A-7 - Physiochemical Variables Measured at Benthic Sample Locations

Sample ID	Depth (feet)	Temp. (°C)	Water pH	Conductivity (mS/cm)	Turbidity (NTU)	Flow (feet/sec)	Percent of Sample								TOC (mg/kg)	Ammonia (mg/L)	Chloride (mg/kg)
							Gravel	Coarse Sand	Medium Sand	Fine Sand	Fines	Coarse Sediment	Silt	Clay			
BC-T17-50	27	10.45	8.1	0.191	8.6	1.42	15.0	21.6	28.8	25.2	9.4	65.4	6.7	2.7	8,530	0.34	5.0
BC-T20-175	35	10.34	8.09	0.19	9.1	1.88	6.9	19.0	25.4	17.5	31.1	51.3	23.9	7.2	37,400	1.9	1,190
BC-T22-25	23	10.39	7.99	0.192	9.4	1.09	2.8	3.6	15.4	70.8	7.5	21.8	3.4	4.1	23,800	7.0	57.2
BC-T23-75	26	10.37	8	0.193	12.7	1.21	0.3	0.2	6.3	73.1	20.0	6.8	12.5	7.5	25,100	2.7	32.8
BC-T24-75	26	11.33	7.95	0.19	4.3	1.29	6.3	2.2	9.9	56.1	25.5	18.4	15.9	9.6	6,950	4.6	42.5
BC-T25-50	20	11.39	7.98	0.192	4.2	0.5	0.0	0.0	1.5	15.2	83.3	1.5	54.0	29.3	40,300	39.7	2.5
BC-T26-50	19	11.41	8.05	0.193	4.0	0.74	0.0	0.0	4.4	25.2	70.3	4.4	35.0	35.3	39,200	40.1	139
BC-T27-50	19	9.62	8.14	0.189	21.0	1.11	13.8	2.1	5.3	67.8	10.9	21.2	7.6	3.3	22,800	14.9	51.2
BC-T28-125	27	9.61	8.3	0.187	31.4	1.04	8.6	2.2	5.6	78.3	5.4	16.4	3.5	2.0	23,000	2.6	6.2
BC-T29-25	10	9.64	8.15	0.192	15.9	0.3	7.2	1.7	7.2	41.7	42.3	16.1	30.3	12.0	47,000	23.5	254
BC-U04	12	10.27	8.11	0.194	16.7	0.42	1.1	1.3	1.1	83.4	13.2	3.5	6.7	6.5	38,700	59.7	8.8
BC-U07	22	9.75	8.1	0.2	16.7	1.1	7.1	9.7	11.0	69.5	2.7	27.8	0.9	1.8	5,270	2.5	4.3
BC-U08	30	9.74	8.14	0.192	23.9	0.89	1.5	3.2	12.2	46.2	36.8	16.9	28.4	8.4	122,000	19.8	15.2
BC-U10	22	10.3	8.2	0.196	11.3	0.53	0.6	0.7	1.4	89.6	7.8	2.7	4.6	3.2	6,570	7.1	5.7
BC-U11	29	9.68	8.14	0.196	25.2	1.34	12.1	11.0	7.7	62.6	6.6	30.8	3.5	3.1	9,680	2.1	4.6
BC-U12	11	9.62	8.15	0.197	22.5	0.34	0.0	0.3	0.5	71.7	27.5	0.8	17.6	9.9	12,600	44.1	8.6
BC-U13	12	9.67	8.12	0.197	15.0	0.07	0.2	0.2	1.5	92.8	5.2	1.9	2.4	2.8	4,220	7.2	3.5
BC-U14	30	9.73	8.16	0.194	19.2	1.22	10.8	5.8	17.4	48.5	17.5	34.0	12.8	4.7	11,000	1.9	15.7
BC-U15	32	10.29	8.12	0.193	16.0	1.26	0.3	2.1	15.3	71.0	11.2	17.7	6.9	4.3	39,200	4.6	9.3
BC-U16	32	11.49	8.04	0.198	4.2	1.08	2.9	4.2	9.7	79.3	4.0	16.7	2.4	1.6	38,000	2.4	6.25
BC-U17	30	11.47	8.04	0.197	3.6	1.16	6.2	1.3	2.5	71.9	18.1	10.0	11.3	6.8	10,200	2.5	5.5

mg/kg - milligrams per kilogram
mg/L - milligrams per liter
°C - degrees Celcius

mS/cm - microsiemens per centimeter
NTU - nephelometric turbidity units
TOC - total organic carbon

Notes:

1. Physicochemical data were collected concurrently during benthic community sampling from 10 Site locations (BC-T## - ###) and 11 Upstream locations (BC-U##).
2. Surface water quality measurements were taken within one meter of the river bottom to represent benthic community conditions.
3. Grain size, TOC, ammonia, and chloride were measured for samples collected using a box corer sediment sampler (9.65 in x 9.65 in) from the 0-6 inch sample depth.

Table A-8 - Analytical Results for Sediment Samples

Sample ID	Nearest Neighbor[1]	Arsenic mg/kg	Mercury mg/kg	Selenium mg/kg	Thallium mg/kg	Sediment pH SU	Cyanide mg/kg	TPAH mg/kg	Phenol[2] µg/kg	Aluminum mg/kg	Beryllium mg/kg	Lead mg/kg	Vanadium mg/kg	Zinc mg/kg
BC-T17-50	NA	6.36	0.28	0.39	0.27	9.63	2.3	229	409	3,823	0.33	151	11.9	97
BC-T20-175	NA	6.35	0.58	0.73	0.19	10.72	7.5	477	685	4,962	0.49	77	14.1	149
BC-T22-25	NA	6.91	0.73	0.79	0.26	10.69	5.9	479	633	5,580	0.62	96	14.9	197
BC-T23-75	NA	5.37	0.43	0.81	0.20	11.53	7.4	5.8	734	5,861	0.68	37	16.2	83
BC-T24-75	NA	10.85	0.93	1.11	0.44	10.21	5.5	342	544	6,950	0.89	135	17.5	187
BC-T25-50	NA	17.66	1.18	1.21	0.62	9.49	7.0	47	607	7,303	0.76	232	20.3	321
BC-T26-50	NA	14.96	0.97	0.89	0.59	8.92	3.5	46	459	8,295	0.70	286	21.3	552
BC-T27-50	NA	22.31	1.29	1.38	0.90	9.50	3.8	29	450	9,354	0.84	208	19.4	349
BC-T28-125	NA	15.88	1.35	1.63	0.60	9.84	3.4	396	211	7,237	0.68	208	19.2	438
BC-T29-25	NA	13.14	1.29	1.33	0.58	11.01	7.6	34	603	9,806	1.12	190	20.0	354
BC-U04	SD-U02	6.5	0.24	2.00	0.17	8.04	1.0	46	< 340	2,730	0.34	101	11.4	356
BC-U07	SD-U11	12.6	1.00	0.29	0.35	8.15	2.6	49	< 320	5,570	0.44	254	22.3	525
BC-U08	SD-U11	12.6	1.00	0.29	0.35	8.15	2.6	49	< 320	5,570	0.44	254	22.3	525
BC-U10	SD-U11	12.6	1.00	0.29	0.35	8.15	2.6	49	< 320	5,570	0.44	254	22.3	525
BC-U11	SD-U11	12.6	1.00	0.29	0.35	8.15	2.6	49	< 320	5,570	0.44	254	22.3	525
BC-U12	SD-U13	1.5	0.041	1.00	0.063	8.12	0.88	0.87	< 67	1,990	0.14	18.5	8.0	49
BC-U13	SD-U10	6.8	0.28	1.50	0.29	8.16	1.1	60	< 910	6,710	0.46	139	29.5	358
BC-U14	SD-U14	4.9	0.21	0.95	0.13	8.12	1.3	13	< 200	4,610	0.82	92	11.2	252
BC-U15	SD-U21	9.2	0.51	1.50	0.37	8.04	2.0	19	< 250	6,390	0.52	193	19.5	600
BC-U16	SD-U11	12.6	1.00	0.29	0.35	8.15	2.6	49	< 320	5,570	0.44	254	22.3	525
BC-U17	SD-U13	1.5	0.041	1.00	0.063	8.12	0.88	0.87	< 67	1,990	0.14	18.5	8	49

Table A-8 - Analytical Results for Sediment Samples

Sample ID	Nearest Neighbor[1]	PCB µg/kg	Benzene µg/kg	Antimony mg/kg	Chromium mg/kg	Copper mg/kg	4,4-DDE µg/kg	Ethylben µg/kg	Isopropy µg/kg	Toluene[2] µg/kg	Xylenes[2] µg/kg
BC-T17-50	NA	620	15.8	0.35	25	21.8	15.3	20.3	266	55	42
BC-T20-175	NA	458	59.4	0.66	49	42.7	18.5	60.4	306	130	161
BC-T22-25	NA	406	54.4	0.73	80	61.6	27.1	64.5	291	128	152
BC-T23-75	NA	155	105.0	0.28	31	38.2	28.5	96.5	527	178	319
BC-T24-75	NA	305	42.9	0.79	49	67.3	41.4	50.1	152	92	123
BC-T25-50	NA	238	38.7	1.6	138	115.4	24.8	48.1	101	86	233
BC-T26-50	NA	418	34.2	2.1	279	178.5	41.0	72.8	52	93	130
BC-T27-50	NA	225	42.4	2.7	126	134.3	29.5	53.5	400	96	82
BC-T28-125	NA	257	25.4	2.4	86	178.0	62.8	54.0	30	47	69
BC-T29-25	NA	215	62.8	1.8	107	146.3	81.4	69.4	208	118	76
BC-U04	SD-U02	270	54	1.1	81	80.5	12	54	270	81	22
BC-U07	SD-U11	1,200	< 76	2.2	272	197	150	< 76	10	46	34
BC-U08	SD-U11	1,200	< 76	2.2	272	197	150	< 76	10	46	34
BC-U10	SD-U11	1,200	< 76	2.2	272	197	150	< 76	10	46	34
BC-U11	SD-U11	1,200	< 76	2.2	272	197	150	< 76	10	46	34
BC-U12	SD-U13	74	< 50	0.14	16.6	14.9	2.8	< 50	< 250	27	< 150
BC-U13	SD-U10	260	< 110	0.91	72	69.4	32	< 110	< 540	< 220	< 330
BC-U14	SD-U14	240	< 54	0.74	74	56.2	35	< 54	< 270	76	34
BC-U15	SD-U21	890	13	2.2	264	212	24	< 74	< 370	180	41
BC-U16	SD-U11	1,200	< 76	2.2	272	197	150	< 76	10	46	34
BC-U17	SD-U13	74	< 50	0.14	17	14.9	2.8	< 50	< 250	27	< 150

mg/kg - milligrams per kilogram
µg/kg - micrograms per kilogram
NTU - nephelometric turbidity units

PCB - polychlorinated biphenyls
TPAH - total petroleum aromatic hydrocarbons
4,4-DDE - dichlorodiphenyldichloroethylene

Notes:

1. Upstream stations are based on nearest neighbor assignments, which may include nondetects. Site stations are based on interpolations using Inverse Distance Weighting.
2. Nondetects are indicated by "<" qualifier and represent the sample reporting limit. Interpolated results applied to upstream stations are not assigned a data qualifier.

Table A-13 - Multiple Regression Analysis Results for Benthic Community Metrics

Model	Dependent Variable	Model Fit			Best-Fit Model Parameters	p-value	Direction	Importance rank	Notes
		R^2	Adjusted R^2	p-value					
1	Biomass	0.43	0.36	< 0.01	Zinc	< 0.01	–	1	Model explains less than 50% of variance
					Sediment pH	0.02	–	2	
2	Count	0.37	0.34	< 0.01	TPAH	< 0.01	–	1	Model explains less than 50% of variance
3	Total Taxa	0.43	0.33	0.02	Zinc	0.01	–	1	Model explains less than 50% of variance; adding chloride (Cl) gives more predictive model, but Cl is marginally a key variable since it is not quite significant (p>0.05)
					Sediment pH	0.02	–	2	
					Chloride	0.09	+	3	
4	Percent Oligochaetes	0.51	0.39	0.02	Chloride	0.01	–	1	Model explains less than 50% of variance; adding chromium (Cr) gives more predictive model, but Cr is marginally a key variable since it is not quite significant (p>0.05)
					Sediment pH	0.02	+	2	
					Chromium	0.06	+	3	
					Ammonia	0.04	+	4	
5	Percent Chironomidae	0.83	0.80	< 0.01	4,4-DDE	< 0.01	+	1	Adding TOC gives more predictive model, but TOC is not reliably a key variable since it is not significant (p>0.05)
					Chloride	0.03	+	2	
					TOC	0.23	–	3	

AICc = Akaike Information Criterion adjusted for sample size

TOC - total organic carbon

TPAH - total petroleum aromatic hydrocarbons

4,4-DDE - dichlorodiphenyldichloroethylene

Notes:

1. Included significant physico-chemical variables (p<0.1) and all non-collinear analytes (most related to independent variable for pairs of correlated variables) as predictors for analysis.
2. Sediment pH is highly correlated to Area (upstream or site) so both could not be entered into a model. Sediment pH is the better predictor of the benthic invertebrate metrics.
3. Used stepwise regressions to reduce analytes and physico-chemical variables to help reduce variable set, but compared final models using minimum AICc.
4. Lowest AICc recommended (but if within 2 AICc units, models are equally supportable)
5. Importance rank is based on standardized coefficient.
6. Variables highly correlated to parameters in the model (Pearson's r>0.7) also may contribute to effect on dependent variable.
7. Direction of influence is not indicative or perturbation for the following parameters: chloride for Total Taxa model; chloride for Percent Oligochaetes model; and TOC for Percent Chironomidae model.

Table A-14 - Multiple Regression Analysis Results for Benthic Toxicity Endpoints

Model	Dependent Variable	Transformation of Dependent Variable	Model Fit			Best-Fit Model Parameters	Regression Coefficient	p-value	Importance rank	Notes
			R^2	Adjusted R^2	p-value					
1	Biomass Chironomus	None	0.83	0.77	0.002	4,4-DDE	0.0057	0.001	1	Model explains more than 50% of variance
						Aluminum	-0.0014	0.002	2	
						Chloride	0.0043	0.037	3	
						Intercept	1.004	0.001		
2	Biomass Hyallela	None	0.67	0.60	0.01	Lab Water pH	-0.031	0.030	1	Model explains more than 50% of variance
						Aluminum	-0.0000056	0.040	2	
						Intercept	0.313	0.010		
3	% Survival Chironomus	Arcsin Square root	0.78	0.70	0.01	Aluminum	-0.00013	0.002	1	Model explains more than 50% of variance, Benzene is a marginal key variable because it is not quite significant (P>0.05)
						River Water Temp	2.82	0.027	2	
						Benzene	0.0045	0.073	3	
						Intercept	-4.751	0.084		
4	% Survival Hyallela	Arcsin Square root	0.71	0.64	0.004	Toluene	-0.007	0.003	1	Model explains more than 50% of variance
						Thallium	-1.49	0.017	2	
						Intercept	1.943	<0.001		

AICc = Akaike Information Criterion adjusted for sample size

TOC - total organic carbon

TPAH - total petroleum aromatic hydrocarbons

4,4-DDE - dichlorodiphenyldichloroethylene

Notes:

1. Included significant physico-chemical variables (p<0.1) and all non-collinear analytes (most related to independent variable for pairs of correlated variables) as predictors for analysis.

2. Used stepwise regressions to reduce analytes and physico-chemical variables to help reduce variable set, but compared final models using minimum AICc.

4. Lowest AICc recommended (but if within 2 AICc units, models are equally supportable--included model with more variables)

5. Importance rank is based on standardized coefficient.

6. Variables highly correlated to parameters in the model (Pearson's r>0.7) also may contribute to effect on dependent variable.

7. Direction of influence is not indicative or perturbation for the following parameters: 4,4-DDE and chloride for Biomass Chionomus model, as well as correlated variables: chromium, copper, lead, vanadium, aroclor 1260, and isopropylbenzene; benzene for % Survival Chironomus model, plus correlate ethylbenzene.

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Wyandotte, MI
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Table A-15 - Multiple Regression Analysis-Key Predictor Variables of Benthic Toxicity and Benthic Community Metrics

Group	Constituent	Potential Footprint Driver from Steps 1-3	Toxicity Bioassays				Benthic Community Metrics				
			Biomass Chironomus	Biomass Hyallela	% Survival Chironomus	% Survival Hyallela	Biomass	Count	Total Taxa	Percent Oligochaete	Percent Chironomidae
Metal	Aluminum	X	–	–	–	–					
	Antimony						–		–		
	Arsenic	X	–	–	–	–					
	Berrylium	X	–	–	–						
	Chromium		+				–		–	+	+
	Copper		+				–		–		+
	Lead	X	+			–	–		–		+
	Mercury	X	–	–	–	–					
	Thallium	X	–	–	–	–					
	Vanadium		+			–	–		–		
	Zinc						–		–		
Miscellaneous	Total Cyanide	X		–							
PAHs	TPAH							–			
PCB	Aroclor 1260		+								+
Pesticide	4,4-DDE	X	+								+
Phenol	Phenol	X		–		–					
VOC	Benzene	X			+						
	Ethylbenzene				+						
	Isopropylbenzene	X	+								
	Toluene	X				–					
WQ Parameter	Bulk Sediment pH	X		–			–		–	+	
	Lab water pH			–							
	River Water Temp				+						
	Ammonia									+	
	Chloride		+						+	–	+
	Total Organic Carbon										–
	Dissolved oxygen			–							

Notes:

1. Boxes in gray with + or - were variables not in the regression but highly correlated to a variable in the model.
2. + = positive correlation with benthic metric; - = negative correlation with benthic metric.
3. For biomass of Chironomus, Al is correlated to As, Be, Hg, and Tl; 4,4-DDE is correlated to Vn, PCB-1260, isopropylbenzene, Pb, Cu, and Cr.
4. For biomass of Hyallela, Al is correlated to As, Be, Hg, and Tl. Lab water pH is correlated to dissolved oxygen, bulk sediment pH, CN, and phenol.
5. For survival of Chironomus, benzene is correlated to ethylbenzene; Al is correlated to As, Be, Hg, and Tl.
6. For survival of Hyallela, Tl is correlated to As,Al, Pb,Vn, Hg; Toluene is correlated to (phenol)

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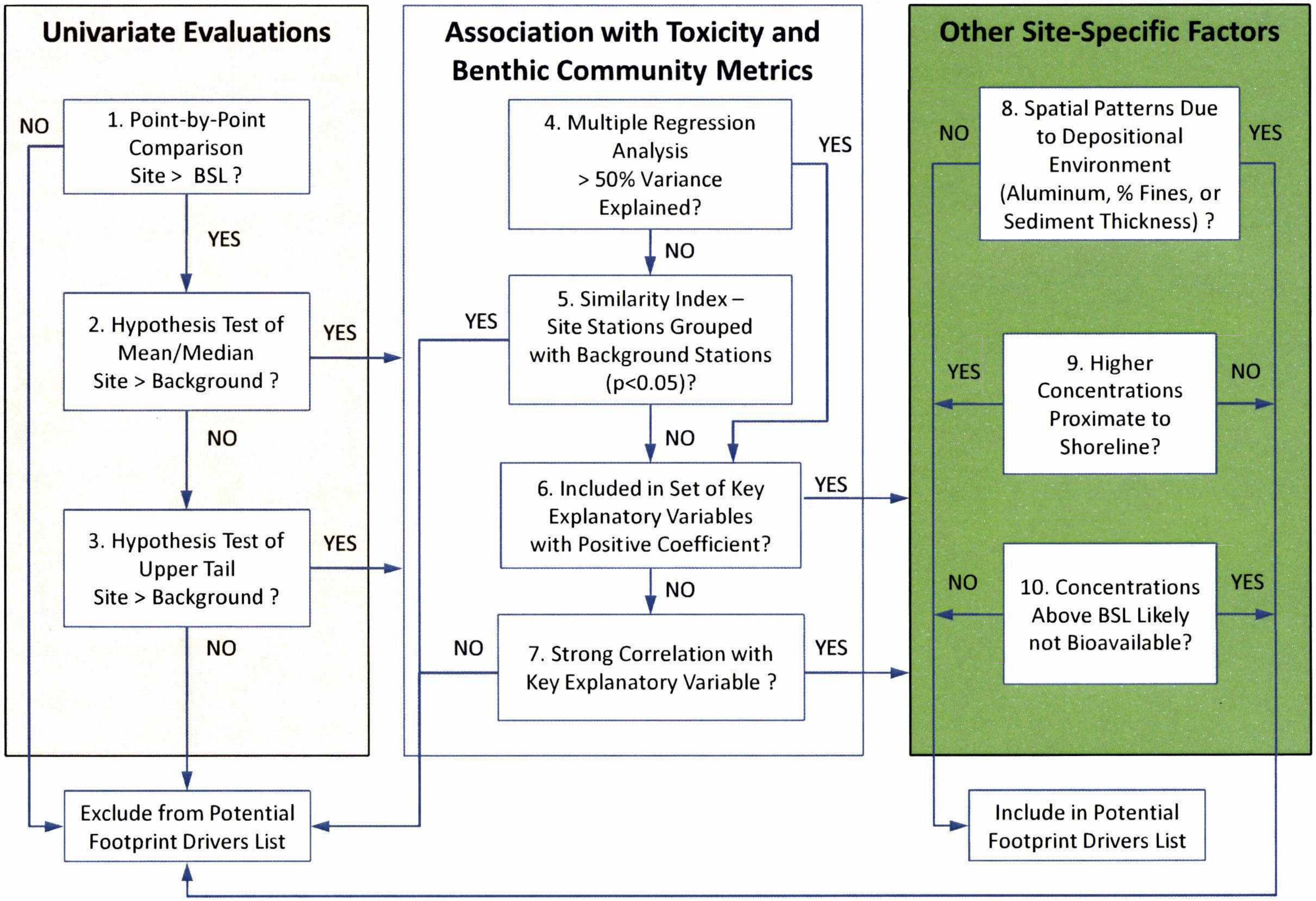
Figures



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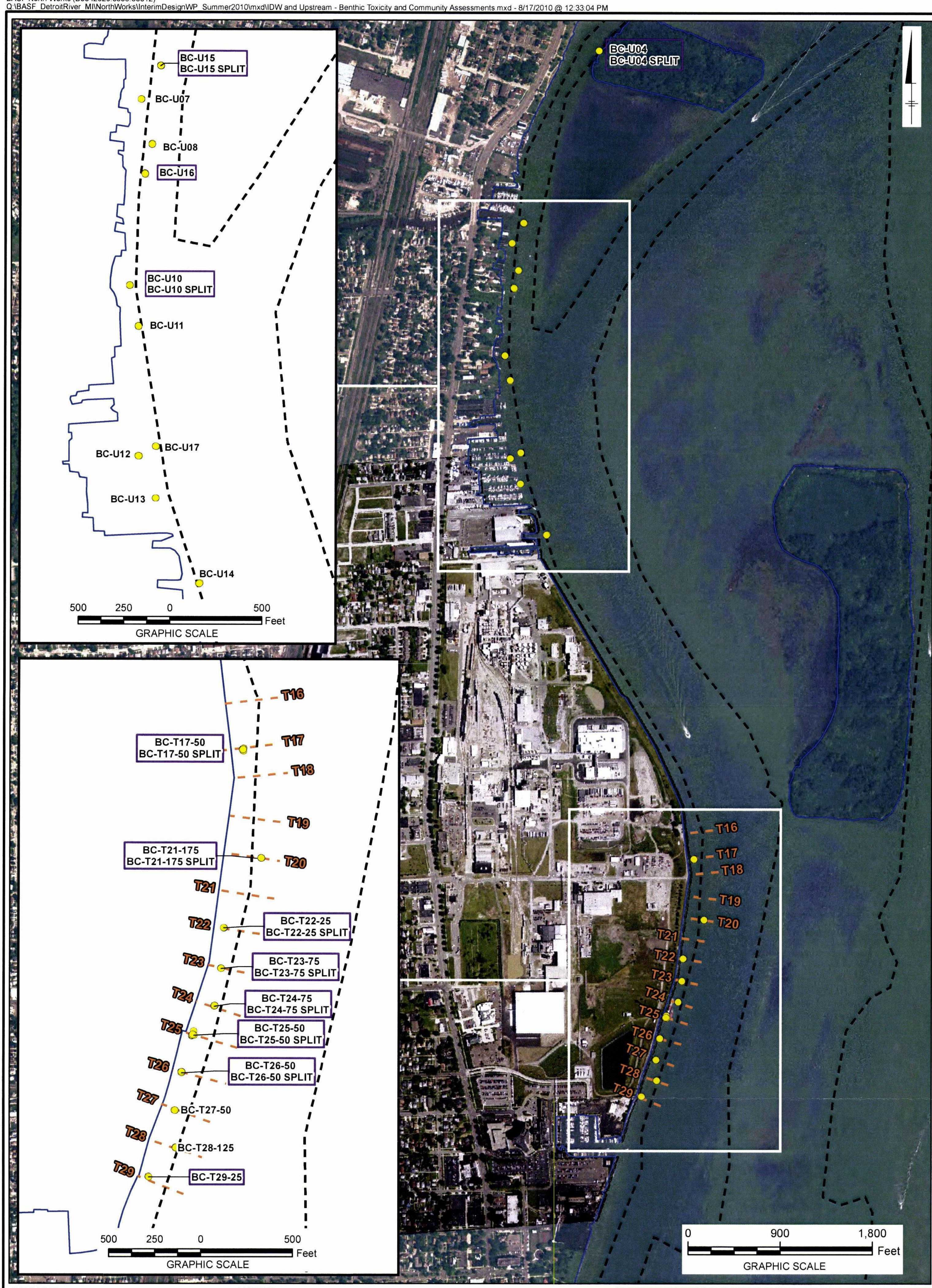
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS
APPENDIX A - PROJECT FOOTPRINT DEVELOPMENT

DECISION TREE FOR PROJECT FOOTPRINT DRIVERS

ARCADIS

FIGURE
A-1

CITY: SYR DIV/GROUP: AIT DB: KEW EAL LD: PIC: PM: TM: TR:
BASF North Works (B0042929.0005.00012)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\IDW and Upstream - Benthic Toxicity and Community Assessments.mxd - 8/17/2010 @ 12:33:04 PM



LEGEND:

- BENTHIC SAMPLE LOCATION
- CORE COLLECTION TRANSECT
- NAVIGATION CHANNEL (APPROXIMATE)
- SHORELINE (APPROXIMATE)

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NOTES:

1. BENTHIC COMMUNITY ASSESSMENTS WERE CONDUCTED WITH SAMPLES FROM 11 UPSTREAM STATIONS AND 10 SITE STATIONS SHOWN.
2. BENTHIC TOXICITY TESTING WAS CONDUCTED WITH 4 OF 11 UPSTREAM STATIONS AND 8 OF 10 SITE STATIONS HIGHLIGHTED BY THE PURPLE BOXES AROUND SAMPLE IDS.
3. UPSTREAM STATION BC-U15 IS NEAREST THE ECORSE RIVER AND EXHIBITED INCREASED TOXICITY RELATIVE TO CONTROL GROUPS FOR BOTH SURVIVAL (CHIRONOMUS: 48% VS 92%, HYALELLA: 0% VS 94%) AND BIOMASS (CHIRONOMUS: 0.07 MG VS. 1.3 MG; HYALELLA: 0 MG VS. 1.3 MG).
4. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
5. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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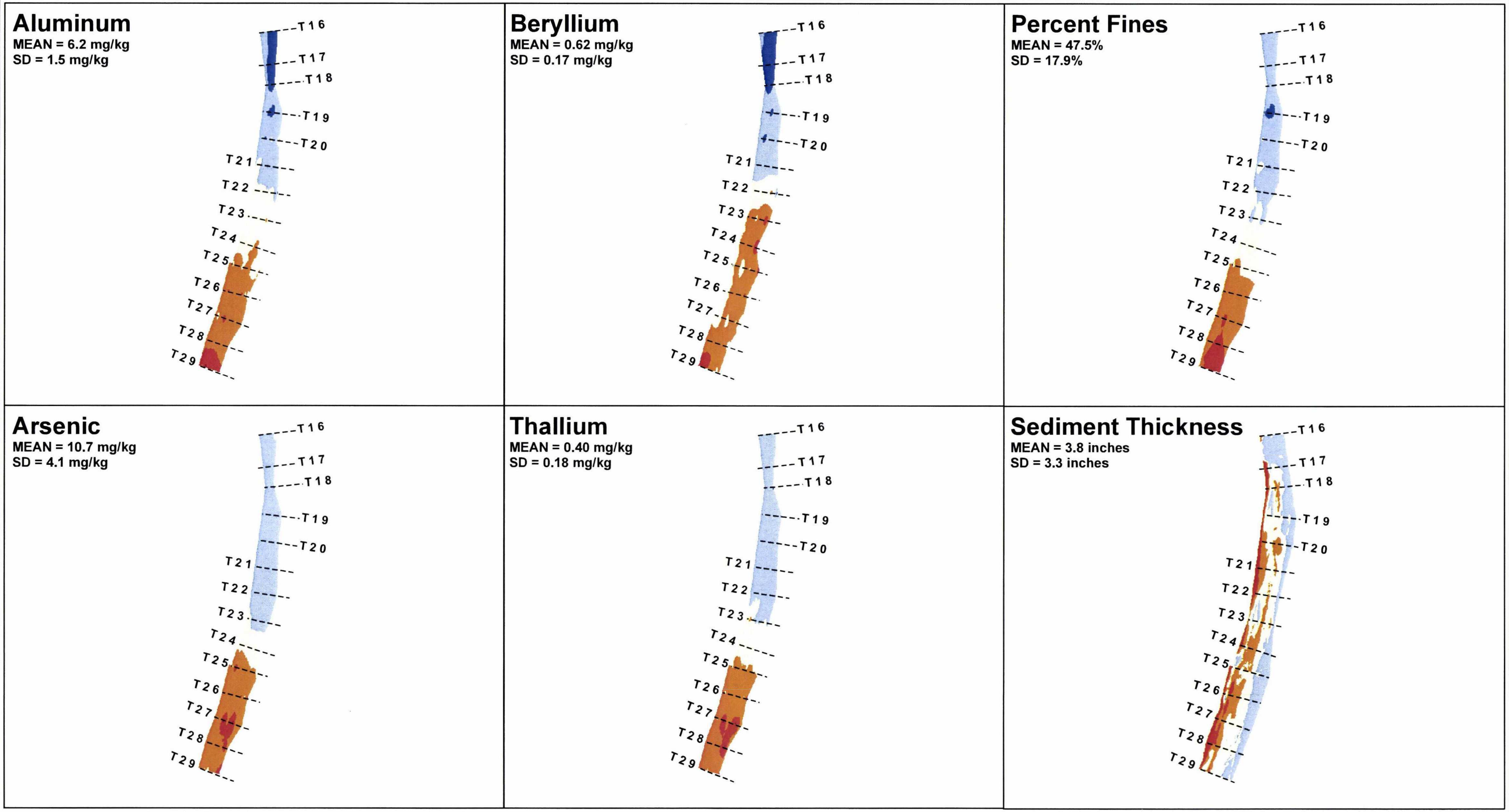
APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

UPSTREAM AND SITE SAMPLING STATIONS FOR BENTHIC TOXICITY AND BENTHIC COMMUNITY ASSESSMENTS

ARCADIS

FIGURE
A-2



LEGEND

- - - - CORE COLLECTION TRANSECT

STANDARD DEVIATION FROM THE MEAN

-2

-1

0

1

2

3

NOTES:

1. CONSTITUENT AND PERCENT FINES ESTIMATION PERFORMED USING INVERSE DISTANCE WEIGHTING (IDW) WITH ANISOTROPY (3 TO 1 N-S TO E-W) ORIENTED AT A 15 DEGREES AZIMUTH AND OPTIMIZED POWER TERMS.
2. SEDIMENT THICKNESS ESTIMATED BY COMPARING TRIANGULAR IRREGULAR NETWORK (TIN) SURFACES GENERATED FROM BOTTOM OF SEDIMENT DATA AND BATHYMETRY.
3. MEAN = ARITHMETIC MEAN, SD = STANDARD DEVIATION

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0 375 750 1,500 Feet

GRAPHIC SCALE

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Interim Measures Design Work Plan – Sediments
Appendix A – Project Footprint Development

VARIATION IN SEDIMENT DEPOSITION AND METALS CONCENTRATIONS - SURFACE (0-0.5 FT)

ARCADIS

FIGURE **A-3**

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
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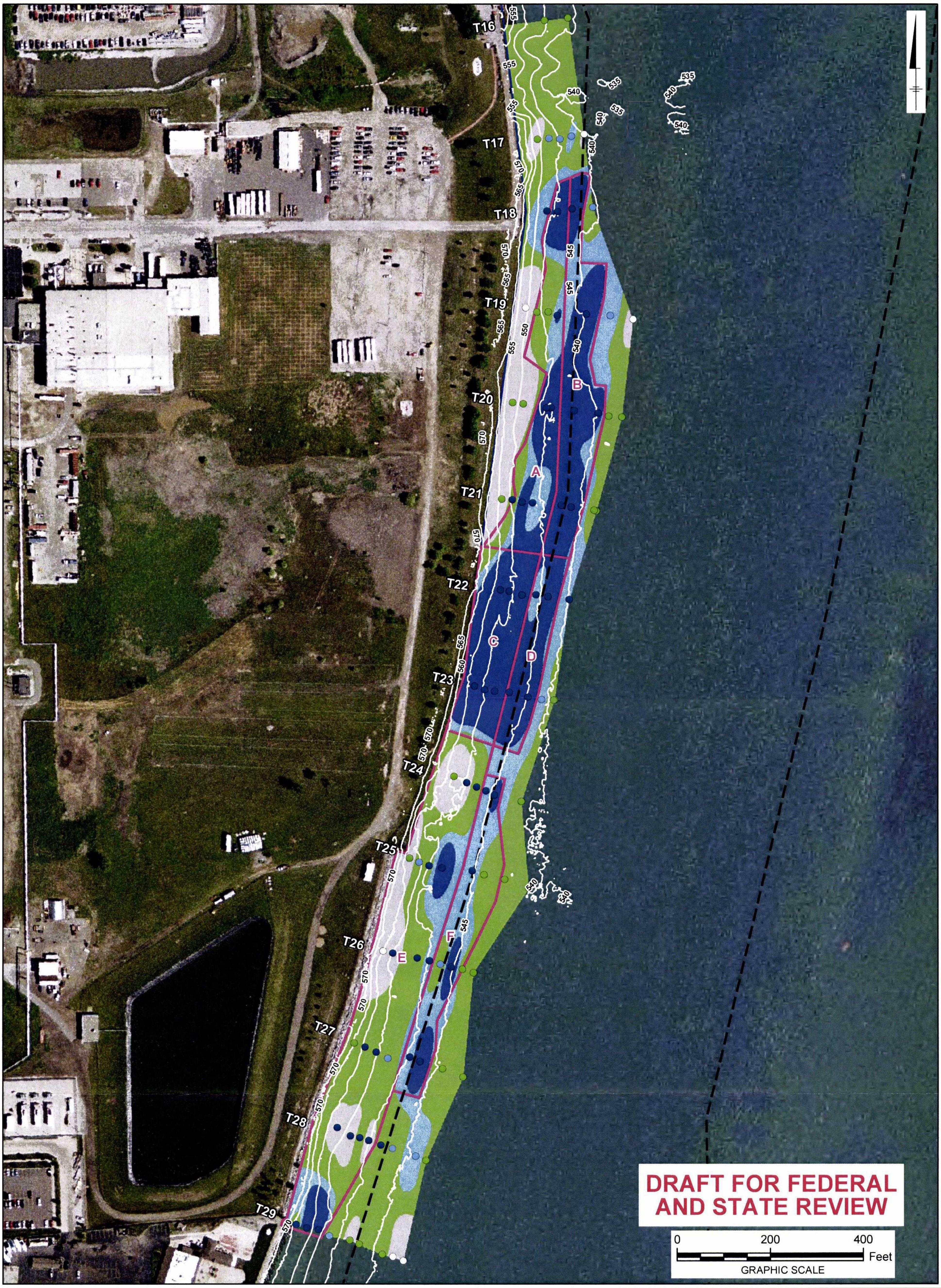

LEGEND:

SEDIMENT CORE MAXIMUM RESULT (mg/kg):
- < 9
- 9 - 10
- 10 - 10.5
- > 10.5

pH RESULTS (mg/kg):
- < 9
- 9 - 10
- 10.5
- > 10.5

- SUBAREA (CONSTRUCTIBLE)
- 2009 BATHYMETRY CONTOURS (5 FT)
- NAVIGATION CHANNEL (APPROXIMATE)
- SHORELINE

NOTES:
1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS
APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

IDW INTERPOLATION RESULTS FOR BULK SEDIMENT SURFACE pH

ARCADIS

FIGURE
A-4

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\IDW Interpolation Results - Phenol - Surface_v3.mxd - 8/18/2010 @ 4:01:02 PM

LEGEND:

SEDIMENT CORE MAXIMUM RESULT (mg/kg):
- < 0.275
- 0.275 - 1.25
- 1.25 - 1.75
- > 1.75

PHENOL RESULTS (mg/kg):
- < 0.275
- 0.275 - 1.25
- 1.25 - 1.75
- > 1.75

SUBAREA (CONSTRUCTIBLE)

2009 BATHYMETRY CONTOURS (5 FT)

NAVIGATION CHANNEL (APPROXIMATE)

SHORELINE

NOTES:
1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

IDW INTERPOLATION RESULTS FOR BULK SEDIMENT SURFACE PHENOL

ARCADIS

FIGURE
A-5

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\IDW Interpolation Results - Cyanide - Surface_v2.mxd - 8/17/2010 @ 12:58:55 PM

LEGEND:

SEDIMENT CORE MAXIMUM RESULT (mg/kg):
- < 1.4
- 1.4 - 5.75
- 5.57 - 16
- > 16

CN RESULTS (mg/kg):
- < 1.4
- 1.4 - 5.75
- 5.75 - 16
- > 16

- SUBAREA (CONSTRUCTIBLE)
- 2009 BATHYMETRY CONTOURS (5 FT)
- NAVIGATION CHANNEL (APPROXIMATE)
- SHORELINE

NOTES:
1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS
APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

IDW INTERPOLATION RESULTS FOR BULK SEDIMENT SURFACE CN

ARCADIS

FIGURE
A-6

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\IDW Interpolation Results - Total PAHs - Surface_v2.mxd - 8/18/2010 @ 4:04:59 PM

LEGEND:

SEDIMENT CORE MAXIMUM RESULT (mg/kg):
- < 176
- 176 - 250
- 250 - 500
- > 500

TOTAL PAH RESULTS (mg/kg):
- < 176
- 176 - 250
- 250 - 500
- > 500

- SUBAREA (CONSTRUCTIBLE)
- 2009 BATHYMETRY CONTOURS (5 FT)
- NAVIGATION CHANNEL (APPROXIMATE)
- SHORELINE

NOTES:
1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS
APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

IDW INTERPOLATION RESULTS FOR BULK SEDIMENT SURFACE TOTAL PAH

ARCADIS

FIGURE
A-7

CITY: DIV/GROUP: DB: LD: PIC: PM: TM: TR:
Project (Project #)
Q:\BASF_DetroitRiver_MI\NorthWorks\InterimDesignWP_Summer2010\mxd\IDW Interpolation Results - Toluene - Surface.mxd

LEGEND:

SEDIMENT CORE MAXIMUM RESULT (mg/kg):
- < 0.1
- 0. - 0.15
- 0.15 - 0.32
- > 0.32

TOLUENE RESULTS (mg/kg):
- < 0.1
- 0.1 - 0.15
- 0.15 - 0.32
- > 0.32

- SUBAREA (CONSTRUCTIBLE)
- 2009 BATHYMETRY CONTOURS (5 FT)
- NAVIGATION CHANNEL (APPROXIMATE)
- SHORELINE

NOTES:
1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009

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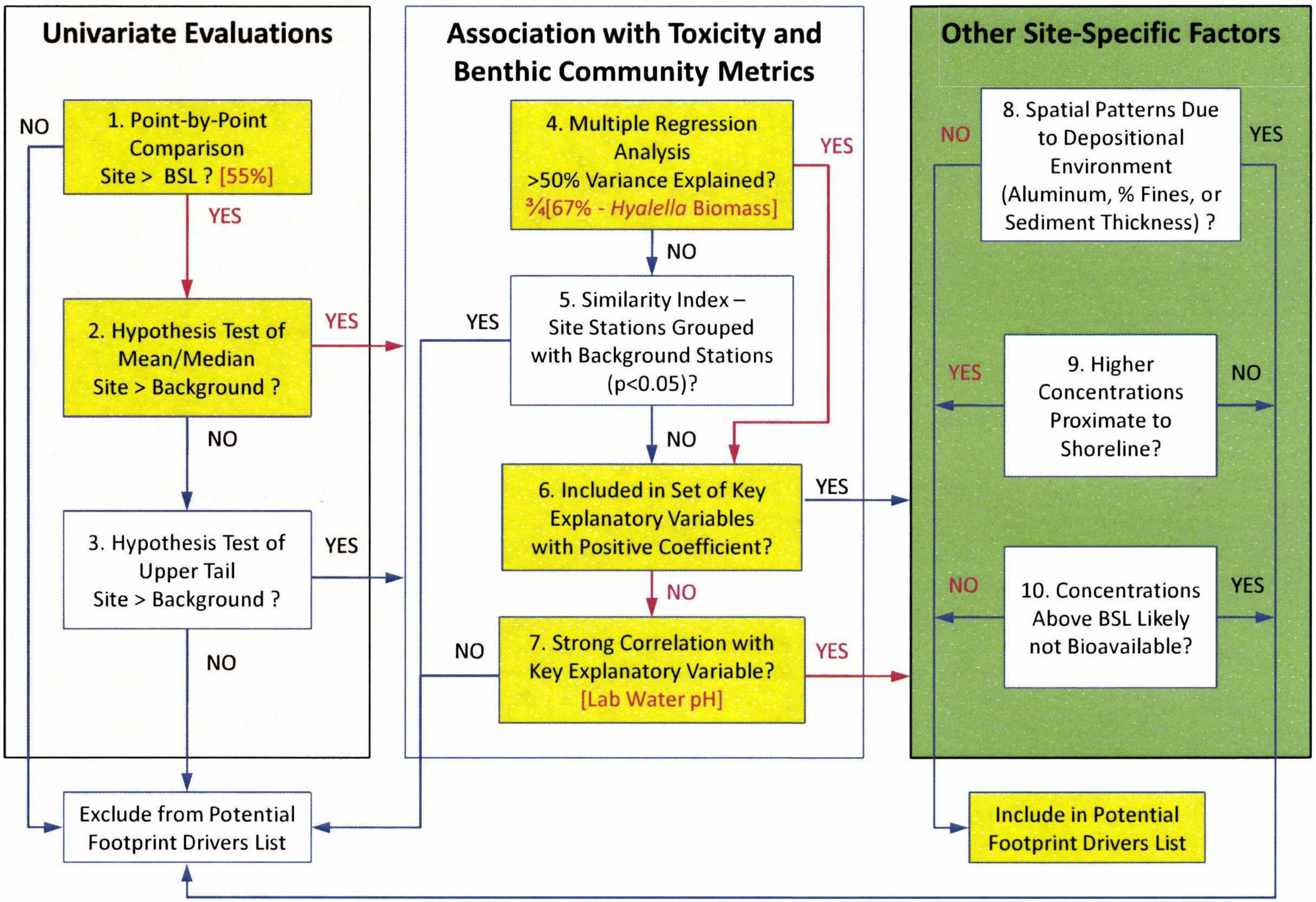
INTERIM MEASURES DESIGN WORK PLAN – SEDIMENTS
APPENDIX A – PROJECT FOOTPRINT DEVELOPMENT

IDW INTERPOLATION RESULTS FOR BULK SEDIMENT SURFACE TOLUENE

ARCADIS

FIGURE
A-8



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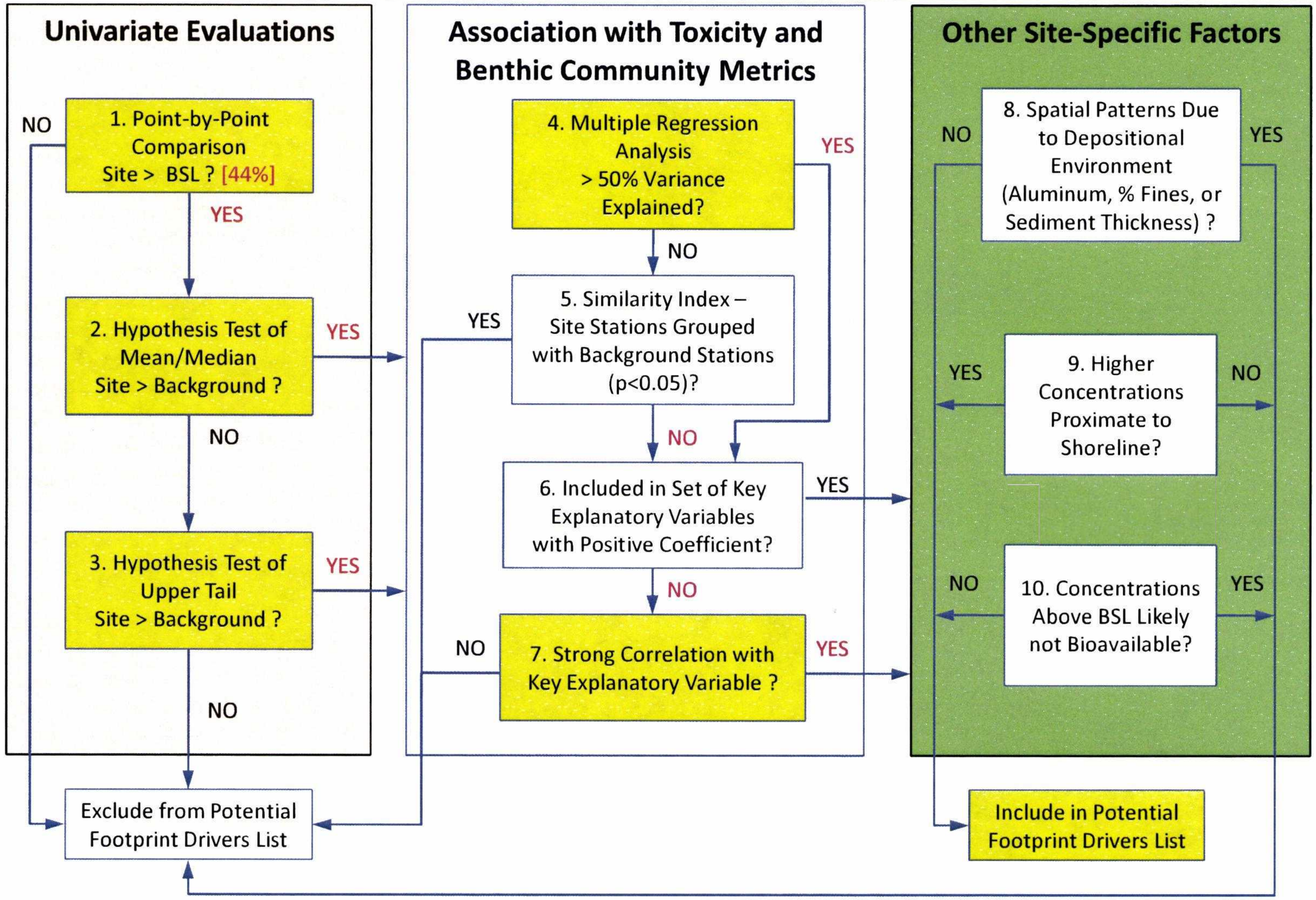
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS
APPENDIX A - PROJECT FOOTPRINT DEVELOPMENT

DECISION TREE FOR PHENOL

ARCADIS

FIGURE
A-18



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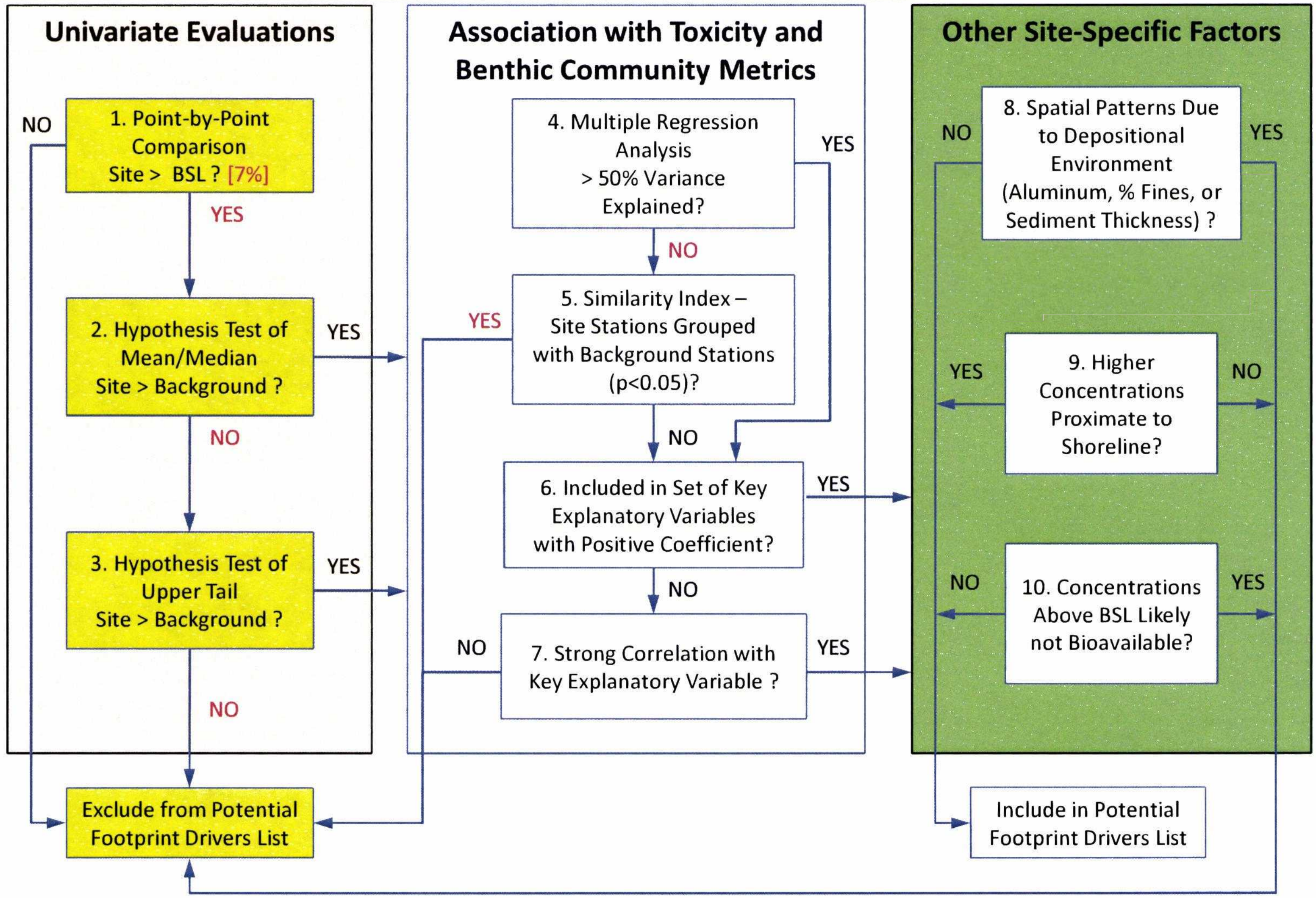
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS
APPENDIX A - PROJECT FOOTPRINT DEVELOPMENT

DECISION TREE FOR BULK SEDIMENT pH

ARCADIS

FIGURE
A-19

08/13/2010 SYRACUSE, NY-ENV/CAD-DJHOWES
B0042929/0008/00002/CDR/42929G19.CDR



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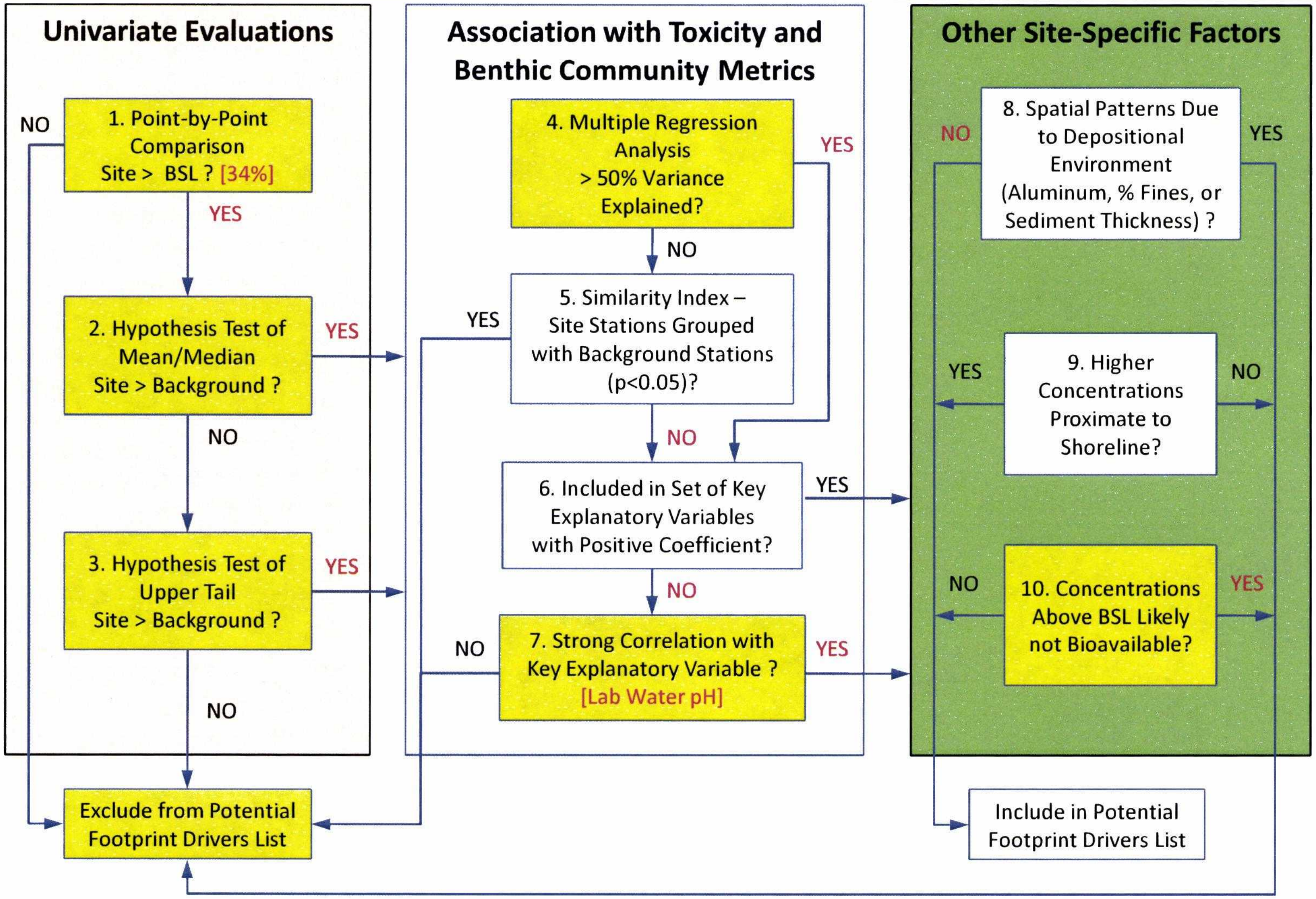
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS
APPENDIX A - PROJECT FOOTPRINT DEVELOPMENT

DECISION TREE FOR TOTAL PAH

ARCADIS

FIGURE
A-20



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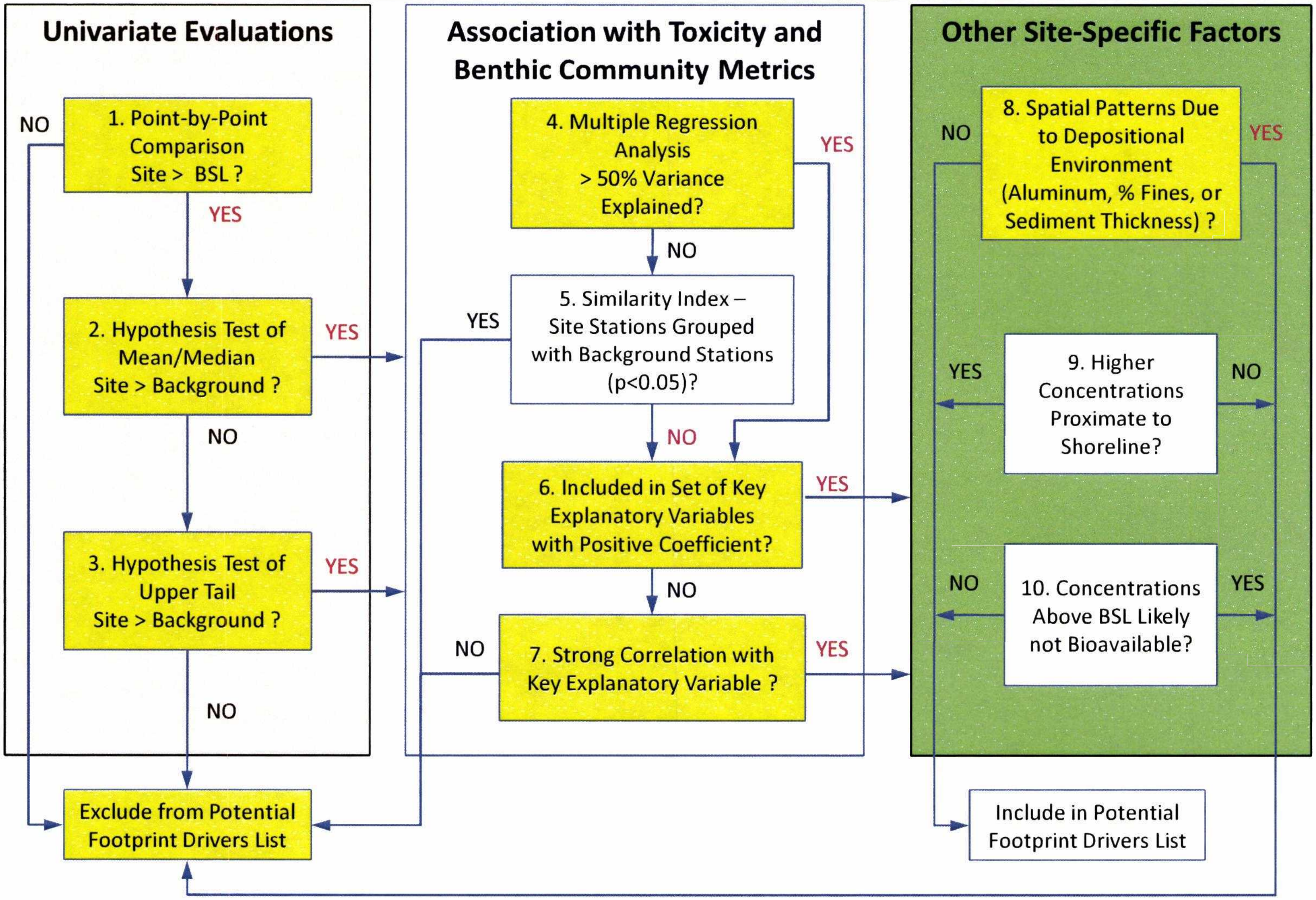
INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS
APPENDIX A - PROJECT FOOTPRINT DEVELOPMENT

DECISION TREE FOR CYANIDE

ARCADIS

FIGURE
A-21



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DECISION TREE FOR METALS

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FIGURE
A-22

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Infrastructure, environment, buildings

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Interim Measures Design Work Plan — Sediments

Appendix B – Bioavailability / Toxicity of Detected CN in Detroit River Sediments

BASF North Works

August 2010

Introduction

The following provides a discussion of cyanide chemistry and the various forms of cyanide that can exist in the environment. The predominant form of cyanide in the Detroit River sediments is believed to be iron-cyanide solids and dissolved iron-cyanide complexes; these are described as well as the technical basis for the chemical speciation of cyanide, which determines its potential bioavailability and toxicity. In this environment, cyanide that is retained in alkaline sediments is tightly bound with iron, and any cyanide that is soluble is likely to be found as an iron-cyanide complex, which is very stable and has low bioavailability and toxicity.

Cyanide in Detroit River sediments may be associated with Prussian Blue (synonym: ferric ferrocyanide), a contaminant of concern (COC) at the BASF Corporation North Works property (the Site) due to historical operations of a gas purification facility by Detroit City Gas Company on a lease parcel in the northwest corner of the Site, and findings of blue-colored material in discrete locations elsewhere on the Site. Thus, sediment samples were analyzed for cyanide; Prussian Blue or ferric ferrocyanide, does not have a standard analytical method and was therefore not measured directly in sediment samples.

Cyanide Chemistry Overview

Cyanide exists as hydrogen cyanide (HCN), cyanide ion (CN^-), or cyanide complexes (e.g., sodium cyanide (NaCN)).

The distribution of cyanide between HCN and CN^- is determined by pH; at pH 9.24 there are equal concentrations of HCN and CN^- in a water sample (Figure 1).

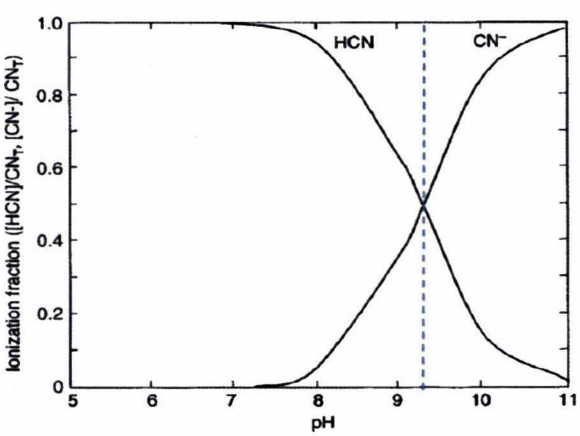

Figure 1. Speciation of cyanide at pH 5-11; at pH values less than 9.24, HCN predominates, while at a pH greater than 9.24, CN^- dominates.

HCN is sometimes referred to as "free cyanide" and is considered the most toxic form of cyanide. It has a very low boiling point (25.7°C) and is therefore very volatile. Due to the high volatility of HCN it will readily form HCN gas, and will therefore partition between dissolved HCN and HCN gas. The equilibrium air-water partitioning is described by Henry's Law. However, while HCN may form and predominates at a pH below 9.24, there are many other reactions that occur in a sediment environment that will result in cyanide taking other chemical forms such as various metal-cyanide complexes (e.g., zinc-cyanide, nickel-cyanide, or iron-cyanide). Above pH 9.24, CN^- predominates and is not volatile; here again it is likely that cyanide will form complexes with other elements that may be present in water/sediment such as iron-cyanide. These complexes tend to be stabilized at high pH (dissociation into metal and cyanide is more likely at acidic pH, depending upon the strength of the complex).

Cyanide Complexes

The cyanide anion is a versatile ligand and readily reacts with metal cations to form metal-cyanide complexes. These species are typically anionic and have the general formula $M(CN)_x^{n-}$. The complexes can be dissociated if the solution is moderately to highly acidic to yield free cyanide as follows:

$$\mathbf{M(CN)_x^{n-} = M^+ + xCN^-}$$

The metal-cyanide complexes are classified into two broad categories: weak metal-cyanide complexes and strong metal-cyanide complexes (Figure 2). The strong metal-cyanide complexes are more stable in solution and dissociate only to a limited extent (or very slowly), and at very acidic pH.

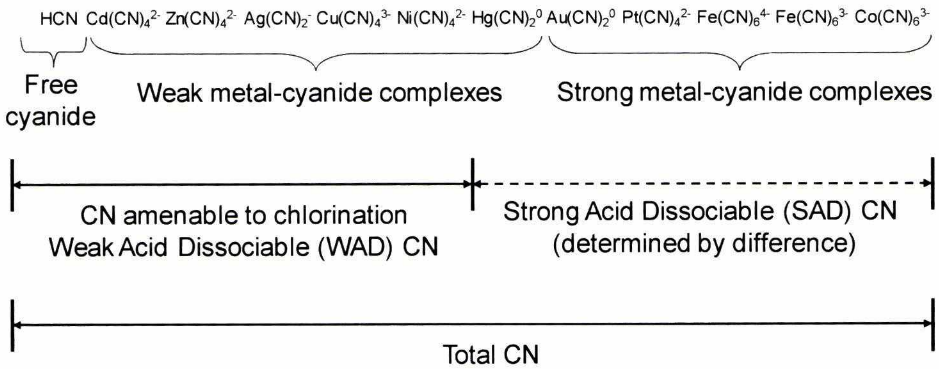

Figure 2. Chemical classification of dissolved inorganic cyanide forms and analytical methods (Dzombak et al. 2006).

Silver and mercury form weak metal-cyanide complexes, as do cadmium, copper, nickel, and zinc (see Figure 2). Weak metal-cyanide complexes dissociate under mildly acidic conditions (solution pH 4 to 6) to produce free cyanide. If the pH remains above ~6, cyanide will remain as a weak metal-cyanide complex.

Strong metal-cyanide complexes form with transition metals such as iron, cobalt, platinum, and gold, and require highly acidic conditions to dissociate and form free cyanide (solution pH <2). These strong metal-cyanide complexes are extremely stable at high pH. These complexes are also much more stable than the weak complexes, and are relatively less toxic because of the strong bond with these metals. Common forms include ferrocyanide (with ferrous iron), ferricyanide (with ferric iron), gold-cyanide, cobalt-cyanide and platinum-cyanide (see Figure 2). If the pH remains above ~2, cyanide will remain as the strong metal-cyanide complex.

In a river sediment environment where iron is naturally abundant in sediment mineral phases, and due to reducing processes where ferrous iron may be dissolved, iron-cyanide complexes can form. These iron-cyanide complexes, such as $Fe[Fe(CN)_6](s)$, or $(Fe_4(Fe(CN)_6)_3)(s)$, have very low solubility at acidic and neutral pH.

Ferric ferrocyanide, $(Fe_4(Fe(CN)_6)_3(s)$ (i.e., Prussian Blue) generally occurs as a solid and is considered a metal-metal cyanide complex. Prussian Blue forms in the river sediment environment through the reaction of cyanide with iron naturally present in soil and sediment. Solids form upon reaction of free cyanide or metal-cyanide species with metal ions, which results in solid precipitation when the reactants are sufficiently abundant. The iron-iron cyanide solids are characterized based on their different proportions of Fe^{2+} and Fe^{3+} (these can be Berlin White, $Fe_2(Fe(CN)_6)(s)$ which contains all Fe^{2+} or Berlin Green, which contains all Fe^{3+}). Prussian Blue has an intense color due to charge transfer between the different oxidation states. Turnbull's Blue ($Fe_3(Fe(CN)_6)_2(s)$) is another iron-iron cyanide complex that is blue. Prussian Blue is formed in the environment through the following reaction:

$$4Fe^{3+} + 3Fe^{2+} + 18CN^{-} = Fe_4(Fe(CN)_6)_3(s)$$

Turnbull's Blue is formed through the following reaction:

$$2Fe^{3+} + 3Fe^{2+} + 12CN^{-} = Fe_3(Fe(CN)_6)_2(s)$$

These can also form through the reaction of ferric or ferrous iron with ferricyanide ($Fe(CN)_6^{3-}$) or ferrocyanide ($Fe(CN)_6^{4-}$) complexes.

Regardless of how they are formed, both forms of iron-iron cyanide solids have very low solubility. The solubility product (log K_{sp}) for Prussian Blue has been reported to be -84.5 (Meeussen et al. 1992a) to -263.30 (extremely low solubility). The solubility is dependent on pH and redox potential. Figure 3 provides a chemical speciation diagram for the solid and aqueous forms of iron-cyanide across pH and Eh.

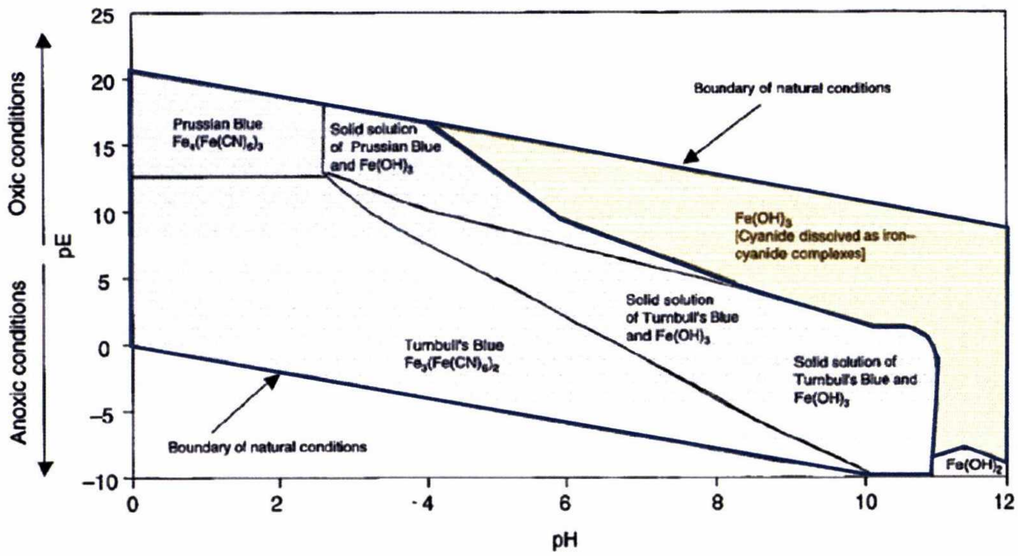

Figure 3. Predominance diagram of iron-iron cyanide solids and soluble iron cyanide complexes across pH and Eh (pE, shown on y-axis).

The dissolution of the iron-iron cyanide solids does not release free cyanide under environmental conditions. The products of dissolution are iron cyanide complexes, as follows (Ghosh et al. 1999):

$$Fe_4(Fe(CN)_6)_3(s) = 4Fe^{3+} + 3Fe(CN)_6^{3-}$$

The ferrocyanide ($Fe(CN)_6^{3-}$) that is released is a very strong metal-cyanide complex and therefore does not easily dissociate into free cyanide, and requires a strong acid to release cyanide.

Strong acid dissociable cyanide complexes, including ferric cyanide, can often be the main constituents of the total cyanide concentration. These complexes will dissociate only in very acidic (pH<2) solutions and are otherwise stable, even relative to biodegradation. Published studies of ferric cyanide, specifically the hexacyanoferrates ($Fe(CN)_6^{3-}$ and $Fe(CN)_6^{4-}$) show that they remain as strong complexes in groundwater and soil environments for 100 – 1,000 years at near neutral pH (Meeussen et al. 1992b). These complexes can photodegrade when exposed to sunlight. Photolysis has been shown to be important only in the top 50 - 100 centimeters of a water column where sunlight intensity may be sufficient; and any free cyanide produced would undergo significant dilution (Dzombak et al. 2006).

Conceptual Model for the Formation of Cyanide Complexes in Detroit River Sediments

- The analysis used to determine cyanide was a total cyanide method. This method quantifies all of the cyanide in the sample and does not identify various forms of cyanide that may be present. At strongly acidic conditions (pH < 2) the Prussian Blue will dissociate and release cyanide.

- Contact of cyanide with alkaline sediment will result in the formation of iron-cyanide complexes.

- Cyanide is retained in alkaline sediment as iron-cyanide complexes and precipitates (e.g., insoluble iron-cyanide (Prussian blue)). Cyanide is tightly bound in sediments with iron and the formation of free cyanide (HCN) is prevented.

- Cyanide that is soluble in the sediment is likely to be present as iron-cyanide complexes, which are very stable and have low bioavailability/toxicity.

- Multivariate analysis identifies cyanide as a minor explanatory variable for benthic toxicity but not for benthic community metrics. Specifically, a multiple regression model that explains about 60% of the variance in *Hyallela* biomass identifies lab water pH as one of two primary explanatory variables, and cyanide is moderately correlated with lab water pH (Pearson $r^2 = 0.6$) (see Appendix A). For the same subset of samples used in toxicity testing, cyanide is also moderately correlated with bulk sediment pH ($r^2 = 0.8$), beryllium ($r^2 = 0.4$) and phenol ($r^2 = 0.4$), none of which were primary explanatory variables of regression models for benthic organism growth and survival. Cyanide is not a significant variable in any of the cluster analysis results that identified factors that explain similarities in toxicity and benthic community metrics across upstream and Site locations.

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BASF Corporation
Wyandotte, Michigan

Interim Measures Design Work Plan — Sediments

Appendix C - Geochemistry of Pore Water Alkalinity Neutralization

BASF North Works

August 2010

Introduction

The purpose of this appendix is to provide insight into naturally occurring geochemical reactions that will help neutralize alkalinity released from alkaline-impacted sediments. As will be shown, reactions with atmospheric carbon dioxide and products of bacteriogenic processes will provide sources of acidity that collectively result in an important inventory of base-consuming reactants.

Pore water alkalinity associated with dissolution of salts in Detroit River sediment adjacent to North Works is attenuated by various alkalinity neutralization processes, such as those associated with atmospheric gaseous carbon dioxide [CO_2], diagenesis of organic materials, oxidation of ferrous iron present within riverine sediments, and diffusion/advection processes in the porous surficial habitat layer of the Detroit River bottom. The characteristics of this surficial layer have been documented by pore water sampling, sediment profile camera surveys and various sediment sampling techniques. The geochemical reactions that cause attenuation of alkalinity, specifically elevated pH levels, have been well documented by others. An additional important factor in this is the bulk sediment pH measurement protocol, which alters in-situ conditions due to the following: 1) vibracoring significantly alters the physical consistency and integrity of the surface sediment layer, 2) capping and storage of the vibracores causes the oxygenated surficial layer to become anoxic due to diagenetic consumption of dissolved oxygen, 3) the sub-sampling of core intervals and subsequent aggressive mixing to homogenize the sample further destroys the integrity of the sediment and may reactivate passivated surfaces (as explained below), and 4) the addition of an amount of water to "wet" the sample adequately for pH probe readings may not represent the actual quasi-steady-state mixing volumes present in surface sediments. This quasi-steady state would be determined by the rate of diffusion/advective fluxes due to interaction with the flowing overlying river water.

The combined effect of the influences identified above is that in-situ pore water pH levels will be decreased from bulk sediment pH levels, which has been shown by various water and bulk sediment pH measurements available to date from site investigations at North Works.

The remainder of this document presents a summary geochemical process explanation for the observed discrepancy between in-situ pore water and bulk sediment pH readings.

Alkalinity Neutralization Reactions

Atmospheric gaseous carbon dioxide [CO_2], when dissolved in water, provides an important and essentially inexhaustible reservoir of acidity (Stumm and Morgan 1970). Gaseous carbon dioxide is transferred into a dissolved aqueous phase through diffusion and/or advective processes; the latter, for example, by aeration or other turbulence-inducing process associated with the flow of the river water. During turbulence-induced mixing of ambient air and river water, other gases (including oxygen [O_2]) will also be dissolved and will also be transferred by diffusion-controlled processes. Detroit River water dissolved oxygen levels tend to run near saturation concentrations, driving diffusion of oxygen into non-oxygen-saturated regimes such as the underlying alkaline-impacted sediments where the oxygen can generate acidity (as will be discussed below). Upon dissolution, carbon dioxide will react forming an equilibrium distribution of carbonate species via the following geochemical reactions (Stumm and Morgan 1970; Berner 1971):

1. $CO_2 + H_2O = H_2CO_3$
2. $H_2CO_3 = H^+ + HCO_3^-$
3. $HCO_3^- = H^{+} {}^{+} CO_3^{-2}$

Under initially alkaline conditions, progressive dissociation of the carbonate ion yields hydrogen ion providing a source of acidity; this acidity can then help neutralize sources of alkalinity in water and sediment due to exchange of water and dissolved constituents across the sediment-water interface. This would include pore water alkalinity that can be derived from the dissolution of calcium hydroxide [$Ca(OH)_2$] present within alkaline-impacted sediments via the following reaction:

4. $Ca(OH)_2 = Ca^{+2} + 2OH^-$

Dissolved carbonate species and oxygen present in the river water may be transferred by both advective flow and diffusion into the underlying Detroit River sediments, along with the transferral of calcium and hydroxide ions from the alkaline-impacted sediment lying beneath them. Due to the presumably higher permeability of the Detroit River sediments versus the alkaline-impacted sediment beneath, it is likely that the main mass transfer process for calcium and hydroxide ion is by the comparatively slower diffusion process from the lower permeability alkaline-impacted sediment into the high porosity surficial sediment layer. This high porosity (i.e. silty/sandy/gravely layer) has been documented by sediment profile camera surveys and various types of sediment sampling conducted to date. The basis for the presumption of the higher permeability of the natural river sediment versus the alkaline-impacted sediment is based on two primary lines of reasoning. The alkaline-impacted sediments contain a significant fine-grained chemically formed precipitate resulting in a comparatively low permeability. Additionally, the elevated reactive calcium hydroxide that was, and to a lesser extent, is still present (based on mineralogical identification from x-ray diffraction),will react likely on the scale of minutes with any dissolved phase carbonate ion or atmospheric carbon dioxide if exposed to the air. This will cause significant carbonation and consumption of porosity, and presumably permeability, as discussed below. The mere presence and persistence of calcium hydroxide in an environment in contact with comparatively fresh river water argues that a robust protective mechanism must be active. Calcium hydroxide is quite soluble and would be rapidly and completely dissolved if in full and unimpeded contact with the river water. A factor in the persistence of calcium hydroxide is argued herein to be due to the formation of a protective armoring coating of calcium carbonate.

Surficial exposed alkaline sediments (e.g., those present in an unsaturated state and exposed to the open atmosphere) will quickly undergo carbonation through reaction with atmospheric carbon dioxide. This process is analogous to the carbonation reactions that occur with Portland cement-based concrete forming bridges and abutments. The carbonation in the Portland cement-based concrete stems from reaction between carbon dioxide and calcium oxide or calcium hydroxide present within the concrete. In fact, it is the carbonation reaction that ultimately consumes the alkalinity within the concrete that subsequently removes the protective passivation this alkalinity provides to rebar embedded within the concrete, resulting in its expansive destruction. Carbon dioxide transport into unsaturated sediment exposed to the atmosphere occurs via a gas diffusion process (with a nominally 10,000 fold more rapid rate of gas phase diffusion compared to aqueous diffusion rates) and can result in rapid carbonate of calcium oxy/hydroxide compounds.

These two dissolved constituents (calcium and hydroxide ion) are transferred to the Detroit River sediments, providing for the following predicted and thermodynamically favorable reactions to occur:

5. $H^+ + OH^- = H_2O$
6. $Ca^{+2} + CO_3^{-2} = CaCO_3$

Reaction 5 simply shows the consumption of hydroxide ion emanating from the alkaline sediment by hydrogen ion derived from the dissolution of atmospheric carbon dioxide.

Reaction 6 shows the consumption of calcium ion derived from the alkaline-impacted sediments and carbonate ion derived from the dissolution of ambient air forming the calcium carbonate mineral, calcite [$CaCO_3$]. Data are lacking for the development of a detailed model for the exact vertical location of calcite precipitation in the sediments – assuming a hypothetical static sediment surface with no ongoing deposition. However, due to the faster transport of dissolved carbon dioxide to the Detroit River sediment than dissolution of calcium hydroxide (as a result of greater porosity of the overlying surface layer), calcium ion diffusing from the alkaline-impacted sediment will encounter an environment with dissolved carbonate ion present to foster calcium precipitation immediately above or near the surface alkaline-impacted layer (i.e. at the bottom of the higher porosity overlying layer – which is what sediment profile imagery suggests to be the case in the great majority of locations). For example, the figure below shows a typical profile image from location T25-150:

It is also possible that a discrete layer of calcite forms within the upper portion of the alkaline-impacted layer. Diffusive permeation of dissolved carbonate ion into the alkaline sediment has additional important implications, as discussed below.

Another, additional source of acidity is found with sediments that frequently have the ferrous form of iron [Fe^{+2}] present in oxide and silicate minerals. Ferrous iron reacts with dissolved oxygen forming very low solubility ferric hydroxide [$Fe(OH)_3$] and the release of hydrogen ion (acidity) via the following reaction (Stumm and Morgan 1970):

7. $4Fe^{+2} + O_2 + 10H_2O = 4Fe(OH)_3 + 8H^+$

The production of hydrogen ion via this reaction then becomes available for neutralization of hydroxide ion emanating from the alkaline sediment.

The formation of ferric hydroxide precipitate via Reaction 7 may impart a yellowish or reddish color to the hosting sediment in marked difference to non-oxidized sediment, which often has a grey or otherwise darkish color. This is what sediment profile image photos indicate (see above photo).

Bacterially-mediated sulfate reduction as a step in the organic carbon digenesis process occurring within the anoxic alkaline sediment layer also provides two different sources of alkaline-consuming acidity. Reaction 8 involves the bacterially mediated reduction of dissolved sulfate ion to hydrogen sulfide with a simple carbohydrate (shown as CH_2O) to produce bicarbonate ion (Berner 1971).

8. $SO_4^{-2} + 2CH_2O \rightarrow H_2S + 2HCO_3^-$

Whereas the bicarbonate ion might at first be thought to contribute alkalinity to the system, under the elevated pH conditions that are present within the alkaline sediment, this product actually provides localized acidity via release of hydrogen ion. Additionally, dissolved phase hydrogen sulfide produced by Reaction 8 can diffuse upward into the overlying Detroit River sediment and be oxidized through reaction with dissolved oxygen via the following reaction:

9. $H_2S + O_2 \rightarrow SO_4^{-2} + 2H^+$

Note the production of hydrogen ion via this reaction, which then becomes available for neutralization of hydroxide ion emanating from the alkaline sediment.

Passivation of Calcium Hydroxide

As noted above, diffusion of dissolved phase carbonate ion into areas where solid phase calcium hydroxide is present can result in the important "passivation" of the calcium hydroxide. Calcium hydroxide is readily susceptible to "carbonation" via the following reaction (Neville 1997):

10. $Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O$

Reaction 10 documents the process whereby calcium hydroxide is converted into a calcium carbonate (typically calcite) phase. This reaction process occurs at the surface of an individual calcium hydroxide grain, typically forming a "reaction selvage" encompassing the surface of the calcium hydroxide grain with a thin, but nonetheless intact "armoring" of calcite. This armoring process has important implications. Although perhaps only a small mass of calcium hydroxide is converted to calcite, the calcite formation results in the encapsulation of the internal mass of calcium hydroxide preventing, or greatly slowing, any subsequent reaction with the calcium hydroxide. The end result is that effectively a mass of calcium hydroxide has now been converted into a grain of calcite. Preservation of the encapsulating calcite "rind" will minimize further alkaline contribution from the carbonated material. This important passivation process can be reversed or disrupted by aggressive physical mixing of the sediment during sampling, as discussed above in the introduction.

Carbonation of calcium hydroxide as shown in reaction 10 (which is repeated below) also directly results in the loss of porosity.

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O$$

This reaction has only two solid phases: calcium hydroxide[ca(OH)2] and calcite [CaCO3]. One mole of calcium hydroxide is consumed for every mole of calcite that is formed. Therefore a comparison of their respective molar volumes will document any change in solid phase volume. Using the data of Robie et al (1979) the molar volume of calcium hydroxide is 33.056 cubic centimeters per mole (cm^3/mole), whereas the molar volume of calcite is 36.934 cm^3/mole. The increase of the molar volume of the solid phase product versus the solid phase reactant results in a decrease of nearly 4 cubic centimeters per mole of reaction or an increase of 11.7 percent in initial solid phase volume. The volumetric increase due to the carbonation reaction also decreases the permeability of the carbonated product and impedes further mass transport of alkalinity from the cemented product. It is this increase of solid phase volume that results in the cementing of hydrated lime when exposed to dissolved phase carbon dioxide. This process is demonstrated, for example, when Portland cement, which contains significant calcium hydroxide, is exposed to moist air resulting in solidification of the initially powdered cement.

The use of Portland cement as an analogous material for the alkaline impacted sediments present in the river is also supported by the x-ray diffraction-based identification of the minerals ettringite and thaumasite; minerals commonly found within Portland cement-based concrete. Portland cement-based concrete has, through a formulated design, a high residual alkalinity in order to prevent destruction oxidation of steel rebar embedded within the concrete. Portland cement is a well accepted reagent for treatment of certain hazardous wastes, such as those containing elevated metals, in both in-situ and ex-situ applications. In-situ applications of Portland cement-based reagents may involve injection of this material into the subsurface where it will contact ground and surface water. Additionally, bridge foundations and piling are constructed of Portland cement-based concrete in contact with river and marine waters. Yet, core samples penetrating into the Portland cement-based concrete will document the presence of high alkalinity, with pH conditions approaching 13 or more due to the presence of residual potassium and sodium hydroxide along with significantly more calcium hydroxide. This elevated pH condition is designed to be maintained for decades as the loss of this alkalinity directly contributes to the rapid degradation of the concrete, a duration commensurate with that the alkaline sediments have been in contact with the Detroit River water. The preservation of this alkalinity identified only through collection of internal core samples from the sediment is consistent with the geochemical preservation of alkalinity within concrete.

Diffusion-Controlled Mass Transfer through Calcite Reaction Selvage "Rind"

Dissolution of a non-carbonated calcium hydroxide grain is controlled by the mass transfer of calcium and hydroxide ion away from the surface boundary of the grain. The diffusion coefficient for migration of dissolved ions through an aqueous media is approximately 10^{-5} to 10^{-6} centimeters squared per second [cm^2/s] (Berner 1971). However, diffusion coefficients for mass transport through solids, such as calcite, using Portland cement and other solidified products as a surrogate, have a range from approximately 10^{-8} to 10^{-11} cm^2/s. This decrease in the diffusion coefficient results in a multiple order of magnitude decrease in mass transport of hydroxide ion through the calcite armoring layer, which helps explain why the passivation process severely limits further reactivity of the internal mass and the potential for significant release of alkalinity.

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Interim Measures Design Work Plan — Sediments

Appendix D - Origin and Scientific Basis of the U.S. Environmental Protection Agency's Aquatic Life Criterion for pH

BASF North Works

August 2010

Several decades ago, the United States Environmental Protection Agency (USEPA) first published freshwater aquatic life criteria that established an acceptable range of pH values between pH 6.5 and 9.0 (USEPA 1976).

The pH of water is defined as the negative of the base 10 logarithm of the hydrogen ion (H^+) concentration, when the H^+ concentration is expressed in units of moles/liter. Therefore, pH is inversely related to H^+ concentration. By definition, neutral water has a pH of 7.0 (i.e., H^+ concentration is $10^{-7.0}$ moles/liter); acidic water has lower pH values (i.e., H^+ concentrations greater than $10^{-7.0}$ moles/liter), and alkaline water has higher pH values (i.e., H^+ concentrations less than $10^{-7.0}$ moles/liter).

As a consequence of those definitions, the pH of water is also inversely related to acidity. This means that the lower the pH, the higher the acidity of the water; and vice versa.

In contrast, pH is positively related to the hydroxyl ion (OH^-) concentration in the water, wherein pH equals the base 10 logarithm of the OH^- concentration, when the OH^- concentration is expressed in units of moles/liter. This means that the lower the pH, the lower the OH^- concentration, and vice versa.

Because the pH scale is logarithmic, a pH change of 1 unit represents a 10-fold change in H^+ concentration and a corresponding, inverse 10-fold change in OH^- concentration. For example, a change in pH from 7.0 to 6.0 represents a 10-fold increase in H^+ concentration and a corresponding 10-fold decrease in OH^- concentration, whereas a change in pH from 7.0 to 8.0 represents a 10-fold decrease in H^+ concentration and a corresponding 10-fold increase in OH^- concentration.

Although the toxicological effects of low pH water are attributed to excess H^+ ions (Wood 1989), the toxicological cause of elevated pH waters is less well known (i.e., the toxicity might be caused by low H^+ concentration, elevated OH^- concentration, or both). But because the concentrations of H^+ and OH^- are mathematically interconvertible (i.e., $H^+ = 10^{-14}/OH^-$), the criteria can be expressed in terms of H^+ concentration only (i.e., as pH criteria), without worrying about which ion actually causes the toxicity at a specified pH.

Careful consideration of the USEPA criteria for pH indicates that only slightly acidic water of pH 6.5 is acceptable for protection of freshwater aquatic life (i.e., only 0.5 pH units less than neutral, equal to an H^+ concentration only 3.16 times higher than in neutral water), whereas considerably more alkaline water of pH 9.0 is indicated as acceptable for protection of freshwater aquatic life (i.e., 3.0 pH units above neutral, equal to an H^+ concentration 1,000 times less than in neutral water and an OH^- concentration 1,000 times higher than in neutral water).

The USEPA's aquatic-life criteria for pH can be traced back many decades to a qualitative review of the toxicity of low and high pH values to fish that was conducted by the European Inland Fisheries Advisory Commission (EIFAC 1969). In that review, no attempt was made to quantitatively analyze the available elevated pH toxicity tests (i.e., USEPA's standard numerical criteria-derivation procedure was not used); and the review for elevated pH toxicity only dealt with a limited number of fish species ("trout", rainbow trout, brown trout, Atlantic salmon, perch, roach, carp, pike, tench, goldfish, Eurasian minnow, burbot, stickleback). Invertebrates were not discussed in the review, and most of the fish studies cited by EIFAC (1969) probably would not meet current data quality requirements for inclusion in criteria derivation (see below).

In the aquatic life criteria that USEPA published in its "Red Book" soon after the agency was established (USEPA 1976: p. 341), the EIFAC (1969) review was cited as justification for the statement "Based on present evidence, a pH range of 6.5 to 9.0 appears to provide adequate protection for the life of freshwater fish and bottom dwelling invertebrate fish food organisms." Although one pH toxicity study of aquatic invertebrates (caddisflies, stoneflies, dragonflies, and mayflies) was also cited in USEPA (1976: p. 341), that study only dealt with low pH toxicity. Therefore, the upper pH criterion of 9.0 was based solely on the EIFAC (1969) qualitative review of pre-1970 data for fish exposed to elevated pH.

In the updated aquatic life criteria that USEPA (1987) published in its "Gold Book" (i.e., an update of the Red Book criteria), the section describing the pH 6.5-9.0 criteria range merely repeated verbatim the pH chapter in the Red Book. Furthermore, the current National Recommended Water Quality Criteria document (USEPA 2006; and annual updates on the USEPA website) cites the Gold Book as the reference for the pH 6.5-9.0 criteria range. Therefore, a formal numerical criteria derivation using the standard USEPA procedure (Stephan et al. 1985) has never been performed for pH with any data, using either pre-1970s data or an up-to-date dataset. Moreover, no invertebrate data has ever been used to determine the upper pH criterion of 9.0.

ARCADIS searched USEPA's Ecotox database and Google Scholar to locate toxicity data for aquatic invertebrates exposed to elevated pH. Although a more thorough search could be conducted, these searches suggest that very little data exist. In fact, ARCADIS found definitive elevated pH toxicity data for only four species: *Daphnia* *galeata* (a cladoceran), *Daphnia magna* (a cladoceran), *Hyalella azteca* (an amphipod), and *Polycelis nigra* (a flatworm). *Hyalella azteca* and *Polycelis nigra* are the only two of those four species that live on or in sediments. The incipient lethal concentration (i.e., the LC50 at >60 hours) for *Polycelis nigra* was pH 9.6 (Jones 1941); and the lethal elevated pH for 4-day exposure of *Hyalella azteca* was $\geq$10 (Yee et al. 2000). For *Daphnia magna*, the 100-hour EC50 (median effect concentration) for immobilization (the standard endpoint for acute toxicity with daphnids) was pH 9.5 (Freeman and Fowler 1953). For *Daphnia galeata*, the threshold for mortality was between 10.5 and 11.5, but reproduction (as measured by egg mortality and stillborn neonates) was impaired at pH 10.0 (Vijverberg et al. 1996). A fifth species [a midge (i.e., an insect) in the genus *Chironomus*] was also studied by Yee et al. (2000); however, because its survivorship was not decreased in any elevated pH waters tested, it's 4-day LC50 was not specifically determined. Moreover, for both *Hyalella azteca* and the *Chironomus* species tested by Yee et al. (2000), the separate effects of elevated Ca concentrations, elevated pH, and concomitant precipitation of Ca minerals could not be isolated in that study, leaving the reported lethal elevated pH levels questionable.

According to the criteria-derivation guidance in Stephan et al. (1985), the following are required in order to derive a numerical criterion for freshwater organisms:

1. Results of acceptable acute toxicity tests with at least one species of freshwater organism in at least eight different taxonomic families, such that all of the following are included:

    a. a fish in the family Salmonidae (a taxonomic family of fish that includes all the salmon and trout species).

    b. a fish in a second family in the class Osteichthyes (the bony fishes), preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.).

    c. a third family in the phylum Chordata (i.e., in a taxonomic family of fish, amphibian, aquatic reptile, aquatic bird, or aquatic mammal, although the latter three groups are less likely to be tested).

    d. a planktonic crustacean invertebrate (e.g., a cladoceran, copepod, etc.).

    e. a benthic crustacean invertebrate (e.g., an ostracod, isopod, amphipod, crayfish, etc.).

f. an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc., all of which are invertebrates).

g. a family in a phylum other than Arthropoda (the phylum that includes all the invertebrates mentioned in 1d, 1e, and 1f) or Chordata (the phylum that includes all fish, amphibians, reptiles, birds, and mammals, and a few invertebrates that are not commonly used in toxicity tests); therefore, test organisms that would meet this requirement include rotifers, annelids, mollusks, etc.

h. a family in any order of insect or any other phylum not already represented.

2. Acute-chronic ratios (thus requiring paired acute and chronic toxicity tests on the same species) for species of aquatic animals in at least three different families, provided that of the three species:

   a. at least one is a fish.

   b. at least one is an invertebrate.

   c. at least one is an acutely sensitive freshwater species (implying that 2a and/or 2b could be a saltwater species).

Therefore, even if the toxicity dataset for fish was acceptable to meet requirements 1a, 1b, and 2a (and possibly 1c and 2c), the current invertebrate toxicity dataset probably is insufficient for derivation of a numerical criterion for elevated pH. Specifically, although requirements 1d (either of the two *Daphnia* species), 1e (*Hyalella*), and 1g (*Polycelis*) might at first appear to be met, the lack of adequate quality assurance/quality control (QA/QC) reporting in the *Daphnia magna* and *Polycelis* studies and potential confounding influences in the *Hyalella* study leave only the *Daphnia galeata* study (i.e., only requirements 1d and 2b would be met for invertebrates). Moreover, if the elevated-pH criterion was limited only to invertebrates, acute toxicity tests may be required on more than just four or five aquatic invertebrate species and paired acute and chronic tests on more than one aquatic invertebrate species.

In summary, not enough aquatic invertebrate species have been tested to establish a valid numerical elevated-pH criterion for invertebrates alone or for fish and invertebrates combined.

Because only two benthic species (*Hyalella azteca* and *Polycelis nigra*) appear to have been tested for elevated pH toxicity (and those data probably would not be acceptable), many more species may have to be tested to establish a defensible criterion for benthic invertebrates.

As mentioned above, USEPA's elevated pH criterion of 9.0 is based on a narrative literature review published by the EIFAC four decades ago (EIFAC 1969). Their summary statements about the toxicity of pH values greater than 9.0 are listed in Table 1.

Table 1 - Summary Narrative Statements in EIFAC (1969), About the Toxicity of Elevated pH to Fishes

pH range	Effect
9.0-9.5	Likely to be harmful to salmonids and perch if present for a considerable length of time.
9.5-10.0	Lethal to salmonids over a prolonged period of time, but can be withstood for short periods. May be harmful to developmental stages of some species.
10.0-10.5	Can be withstood by roach and salmonids for short periods but lethal over a prolonged period.
10.5-11.0	Rapidly lethal to salmonids. Prolonged exposure to the upper limit of this range is lethal to carp, tench, goldfish and pike.
11.0-11.5	Rapidly lethal to all species of fish.

The EIFAC (1969) conclusions were based on a review of 24 papers published between 1931 and 1967 (2 in the 1930s, 4 in the 1940s, 9 in the 1950s, and 9 in the 1960s). Although some of those studies were conducted by eminent and careful researchers (e.g., Doudoroff 1957, Cairns and Scheier 1958, Lloyd 1961, Jordan and Lloyd 1964, Sprague 1964), standard good laboratory practices and QA/QC protocols had not yet been established by the 1960s. Therefore, it was not common for researchers to report information to support the validity of their data. Information about the type of pH analysis (e.g., pH paper, pH color wheel, or pH meter), the type of pH electrode (if a pH meter was used), calibration of the analytical instrument/paper (both frequency of pH calibration and pH range of calibration, if performed), and temperature compensation (if any) was usually lacking. Moreover, variability in pH (and other water quality parameters like alkalinity and hardness) of the exposure waters was seldom reported. In one paper in which the variability in exposure-water pH was at least semi-quantitatively reported, Krishna (1953) stated "Since it was found that a particular quantity of water in a glass vessel containing fifty eggs did not change its pH in 6 hr. by more than 1.0 [pH units] towards the acid side, the water of the experimental container was replaced after 6 hr. with fresh water adjusted to the original pH." That tolerance for a wide variation of up to 1.0 pH units would not be acceptable these days for a toxicity test with almost any toxicant, much less when pH is the main parameter of interest. As an aside, Krishna (1953) also did not identify the species of "trout" used in that toxicity test, rendering the study relatively uninformative for establishing a numerical water quality criterion for elevated pH.

Because of the lack of adequate QA/QC reporting in the literature on which the EIFAC (1969) review was based, it is unknown how many of the other studies had similar wide variations in pH values in the exposure waters. Therefore, the studies that were reviewed by EIFAC (1969) and on which the USEPA's current elevated pH criterion is based should be interpreted with caution.

References

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Interim Measures Design Work Plan — Sediments

Appendix E – Cost Estimates

BASF North Works

August 2010

Introduction

This appendix provides preliminary cost estimate details for each of the remedial alternatives presented in Section 4 of the *Interim Measures Design Work Plan – Sediments (IMDWP)*. The costs presented in this appendix have been developed at feasibility study level and are provided for purposes of comparison of the level of effort, schedule, and complexities among different remedy alternatives. The actual costs of pre-remedy, remedy implementation, and post-remedy activities, subcontractors, and equipment for each sediment remedy may be higher or lower than the costs presented herein, within a -30% to +50% range typical of an alternatives analysis.

Cost Estimate Tables

Preliminary costs are calculated using Net Present Value (NPV) for each sediment interim measure (IM) alternative and process options supporting each alternative. Preliminary costs are presented in the following tables:

- Table 1 presents a summary of the calculated NPV of each alternative, with a 4.5 percent discount rate.
- Table 2 presents the detailed costs of IM Alternative 2, monitored natural recovery (MNR). The long term monitoring includes pore water, surface water, and bioassay sampling and is assumed for 30 years (every year for four years, every two years until year twenty, every five years until year 30).
- Table 3 presents the detailed costs of IM Alternative 3, Mechanical Removal with Residual Management. This alternative is shown graphically on Figure 1.
- Table 4 presents the detailed costs of IM Alternative 4, Partial Removal and Cap Placement. This alternative is shown graphically on Figure 2.
- Table 5 presents the detailed costs of IM Alternative 5, Targeted Removal with Cap Placement. This alternative is shown graphically on Figure 3.

Cost Estimate Basis

Capital and annual operation and maintenance (O&M) costs were used to estimate total costs for each IM alternative, with the exception of Alternative 3. O&M costs are not included as a component of Alternative 3 as the remedy does not include the construction of an engineered isolation cap. Capital costs consist of direct (construction) costs and indirect (non-construction and overhead) costs estimated in 2010 dollars. Direct capital costs include costs associated with construction and equipment, access and site preparation, transportation, and disposal. Indirect capital costs include those activities associated with engineering and management and various contingency allowances to account for site unknowns.

O&M costs are post-construction costs required to assess the continued effectiveness of a remedial action and may include operating labor costs, maintenance and materials and labor costs, costs to conduct periodic site reviews, and long term monitoring. O&M costs associated with Alternatives 4 and 5 were estimated for a 30-year period, assuming annual monitoring for the first five years, every three years through year 20, and every five years through year 30, discounted to a NPV in 2010 dollars. The overall cost for each alternative is the sum of capital and discounted annual costs. The discounted costs were calculated based on the NPV methods described in the 2000 United States Environmental Protection Agency (USEPA) guidance document, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*. A discount rate of 4.5% has been selected for the net present worth as compared to the USEPA recommended rate of 7%. The cost estimates provided have an accuracy of +50 percent to -30 percent in accordance with the 1988 USEPA guidance document, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*.

Table 1 presents a summary of the NPV for each of the IM alternatives with a 4.5 percent discount rate (except for Alternative 3; as described above).

The cost for each IM alternative was calculated by estimating unit costs for the following:

- Equipment mobilization and demobilization
- Site preparation
- Construction control measures (i.e., turbidity curtain installation)
- Debris removal
- Remedy implementation (e.g., MNR or dredging and capping)
- Sediment excavation by mechanical means

- Sediment transport by barge to the Pointe Mouillee confined disposal facility (CDF) for disposal
- Placement of a residuals cover layer in excavated areas
- Construction of a new CDF cell at the Pointe Mouillee CDF
- Placement of an engineered isolation cap in specified areas
- Bathymetric surveys
- Installation of sheetpile dock support and a sheetpile deflection wall
- Miscellaneous costs

Direct labor costs were not calculated. Instead, labor costs were integrated into direct unit costs for each IM alternative line item. To the extent practicable, unit costs associated with each line item were confirmed by contractors, material suppliers, professional and similar project experience, or direct correspondences with disposal facilities. The unit costs are considered reasonable based on knowledge of the industry and industry reports, and includes labor, equipment, and materials necessary to complete the line item activities, where specified. Indirect construction costs were estimated as a percentage of subtotal project costs including project/construction management (5% of the subtotal), contractor engineering and administration (10% of the subtotal), and a general contingency (25% of the subtotal).

Critical input data utilized in the development of cost estimates include total project area (and associated volumes) and individual sediment management units for MNR, capping, and dredging. The cost estimates assume that shoreline improvements involve those areas scheduled for sheetpile installation for structural support. Detailed assumptions are provided as footnotes to the cost estimates.

References

USEPA, 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. EPA 540/G/89/004, OSWER 9355.3-01.

USEPA. 2000. A Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-DO-002, OSWER No. 9355.0-75.

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Tables

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Interim Measures Design Work Plan - Sediments
Table E-1 - Summary of Interim Measure Alternatives and Cost Estimates

Interim Measure Alternative	Costs (million)
1 - No Action	$0.0 M
2 - Monitored Natural Recovery	$1.3 M
3 - Mechanical Removal with Residuals Management	$8.5 M
4 - Partial Removal and Cap Placement	$9.9 M
5 - Targeted Removal with Cap Placement	$7.8 M

Notes:

1. These cost estimates have been developed at an accuracy of -30 to +50%, in accordance with USEPA guidance (USEPA, July 2000).

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Interim Measures Design Work Plan - Sediments
Table E-2 - Alternative 2: Monitored Natural Recovery

ITEM NO.	DESCRIPTION	UNIT	NO. OF UNITS (ROUNDED)	UNIT COST	ESTIMATED COST
Capital Costs					
1	Pore water Sampling	LS	1	$33,000	$33,000
2	Surface Water Sampling	LS	1	$54,000	$54,000
3	Bioassay Sampling	LS	1	$25,000	$25,000
4	Reporting	LS	1	$20,000	$20,000
				Subtotal:	$132,000
5	Project/ Construction Management (5%)				$6,600
6	Engineering and Administration (10%)				$13,200
7	Contingency (25%)				$33,000
				Total Capital Cost:	$184,800
				Present Worth Factor (30 years @ 4.5%):	7.23
				Total O&M Cost:	$1,336,774
				Rounded Total:	**$1.3 M**

Units Key: LS = Lump Sum

General Comments:

1. This cost estimate has been developed at an accuracy of -30 to +50%, in accordance with USEPA guidance (USEPA, July 2000).
2. Costs are rounded off as appropriate.
3. Costs represent summary of estimated capital cost associated with individual items.
4. Unit costs are in 2010 dollars and estimated from standard estimating guides (e.g. Means Site Work and Landscape Cost Data, vendors, professional judgment and/or experience from other similar projects).
5. These estimates are developed using current and generally accepted engineering cost estimation methods. Note that these estimates are based on assumptions concerning future events and actual costs may be affected by known and unknown risks including, but not limited to, changes in general economic and business conditions, site conditions that were unknown at the time the estimates were performed, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates and such variations may be material. We are not licensed as accountants or securities attorneys and, therefore, make no representations that these costs form an appropriate basis for complying with financial reporting requirements for such costs.

See assumptions on page 2.

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Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table E-2 - Alternative 2: Monitored Natural Recovery

Notes and Assumptions:

1. Pore water sampling assumes all labor and expenses associated with the deployment, retrieval, collection and analysis of nine porewater samples (1 per acre) using Trident Probe within the remediation footprint. Pore water analyses assumes Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), Polycyclic Aromatic Hydrocarbons (PAHs), Inorganics, Mercury, Ammonia, Total Organic Carbon (TOC), pH, Chloride and Sulfide.

2. Surface water sampling assumes all labor and expenses associated with the collection and analysis of surface water samples from three locations per acre (54 total samples). Two samples will be collected at each location at 0.2 and 0.8 times the total water column depth. Surface water analyses assumes VOCs, SVOCs, PAHs, Inorganics, Mercury, Ammonia, TOC, pH, Chloride and Sulfide.

3. Bioassay sampling assumes all labor and expenses associated with the collection and analysis of sediment samples from 1 location per acre (9 total samples) for laboratory bioassays.

4. Reporting assumes the preparation and transmittal of one annual report summarizing the results of monitoring activities.

5. A 5% allowance is included for project/construction management and is applied to the sum of itemized subtotal capital costs. This allowance includes costs for legal fees, additional permitting (state or local agencies), obtaining access, negotiations, and/or agency oversight.

6. A 10% allowance is included for engineering and administration support and is applied to the sum of itemized subtotal capital costs.

7. A 25% contingency allowance is included to provide for unforeseen circumstances or variability in estimated areas, costs, and is applied to the sum of itemized subtotaled capital costs.

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Table E-3 - Alternative 3: Mechanical Removal with Residuals Management

ITEM NO.	DESCRIPTION	UNIT	NO. OF UNITS (ROUNDED)	UNIT COST	ESTIMATED COST
Capital Costs					
1	Mobilization/Demobilization	LS	1	$221,000	$221,000
2	Site Preparation	LS	1	$20,000	$20,000
3	Deflection Wall	SF	9,000	$30	$270,000
4	Turbidity Curtain Installation	LF	3,800	$45	$171,000
5	Debris Removal	AC	5.6	$10,000	$56,000
6	Sediment Removal Activities	CY	40,600	$75	$3,045,000
7	Residuals Cover Layer	CY	2,200	$35	$77,000
8	Transportation and Disposal at CDF	CY	45,000	$25	$1,125,000
9	CDF Construction	LS	1	$330,000	$330,000
10	Bathymetric Survey	EA	2	$30,000	$60,000
11	Sheetpile Dock Support	SF	24,000	$30	$720,000
				Subtotal:	$6,095,000
12	Project/ Construction Management (5%)				$304,800
13	Engineering and Administration (10%)				$609,500
14	Contingency (25%)				$1,523,800
				Total Capital Cost:	$8,533,100
				Rounded Total:	**$8.5 M**

Units Key: LS = Lump Sum; LF = Linear Foot; AC = Acre; CY = Cubic Yard; EA = Each; SF = Square Foot.

See assumptions on page 2.

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Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table E-3 - Alternative 3: Mechanical Removal with Residuals Management

General Comments:

1. This cost estimate has been developed at an accuracy of -30 to +50%, in accordance with USEPA guidance (USEPA, July 2000).
2. Costs are rounded off as appropriate.
3. Costs represent summary of estimated capital cost associated with individual items.
4. Unit costs are in 2010 dollars and estimated from standard estimating guides (e.g. Means Site Work and Landscape Cost Data, vendors, professional judgment and/or experience from other similar projects).
5. These estimates are developed using current and generally accepted engineering cost estimation methods. Note that these estimates are based on assumptions concerning future events and actual costs may be affected by known and unknown risks including, but not limited to, changes in general economic and business conditions, site conditions that were unknown at the time the estimates were performed, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates and such variations may be material. We are not licensed as accountants or securities attorneys and, therefore, make no representations that these costs form an appropriate basis for complying with financial reporting requirements for such costs.

Notes and Assumptions:

1. Mobilization/demobilization includes mobilization and demobilization of labor, equipment, and materials necessary to perform remedial activities. Estimate assumes 5% of capital costs excluding transportation and disposal related costs.
2. Site preparation cost estimate includes labor, equipment, and materials necessary to perform clearing, install temporary erosion and sedimentation controls, construct staging and access areas, and otherwise prepare the site for construction.
3. Deflection wall cost estimate includes the procurement, transportation and labor and equipment for installation of the deflection wall as the upstream component of the resuspension control system. Cost estimate assumes 60-foot long AZ18-700 sheeting sections, extending a maximum of 150 feet from the shoreline for the purpose of this cost estimate. Installation of deflection wall is assumed from barge.
4. Turbidity curtain installation includes procurement, transportation, labor and equipment associated with installation and removal of turbidity curtain and accessories. Turbidity curtains will be utilized to mitigate potential migration of sediment during construction activities. Turbidity curtains are assumed to encompass the remedial footprint and anchored to the shoreline.
5. Debris removal includes all labor, materials, equipment, and services necessary for handling/removing obstacles and debris (e.g., boulders, remnant concrete slabs, etc.) from remediation areas. Assumes offsite disposal of debris.
6. Sediment removal activities includes all labor, materials, equipment, and services necessary to complete excavation of impacted material. Excavated material will be transported via barge to the USACE Pointe Mouillee confined disposal facility (CDF). Removal of impacted material is assumed using conventional construction equipment (e.g., excavators, cranes equipped with clamshell buckets, etc.). Sediment removal thickness for each Remedial Area (RA) are provided below:
   - RA - A = 4.7 feet
   - RA - B = 3.7 feet
   - RA - C = 5.1 feet
   - RA - D = 4.7 feet
   - RA - E-1 = 5.3 feet
   - RA - E-2 = 6.6 feet
   - RA - F = 3.8 feet
7. Residual cover layer includes procurement and transportation of material necessary for the placement of residual cover layer. Material placement is assumed using a barge and excavator or crane equipped with a clamshell bucket. The layer will consist of a 6-inch thin lift of clean sand material.

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Interim Measures Design Work Plan - Sediments
Table E-3 - Alternative 3: Mechanical Removal with Residuals Management

Notes and Assumptions (continued):

8. Transportation and disposal of dredged material assumes all materials will be disposed in the USACE Pointe Mouillee CDF. Transportation and disposal will occur via hopper barge to CDF. Material will be unloaded and placed in CDF. Disposal volume estimate assumes removed in-situ materials bulked by 10%.
9. CDF construction includes all labor, materials, equipment and services necessary to construct a new cell at the USACE Pointe Mouillee CDF. CDF tipping fee and capping are included in the CDF transportation and disposal cost.
10. Bathymetric survey includes performing an interim and final survey utilizing multi- beam acoustic depth measurement techniques in accordance with the USACE Hydrographic Surveying Engineering Manual (EM 1110-2-1003).
11. Sheetpile dock support wall cost estimate includes the procurement, transportation and labor and equipment for installation of the sheetpile support wall. Cost estimate assumes 60-foot long AZ18-700 sheeting sections supporting the shoreline along the 400 foot excavation boundary. Installation of sheetpile support wall is assumed from barge.
12. A 5% allowance is included for project/construction management and is applied to the sum of itemized subtotal capital costs. This allowance includes costs for legal fees, additional permitting (state or local agencies), obtaining access, negotiations, and/or agency oversight.
13. A 10% allowance is included for engineering and administration support and is applied to the sum of itemized subtotal capital costs.
14. A 25% contingency allowance is included to provide for unforeseen circumstances or variability in estimated areas, volumes, costs, and is applied to the sum of itemized subtotaled capital costs.

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Interim Measures Design Work Plan - Sediments
Table E-4 - Alternative 4: Partial Removal and Cap Placement

ITEM NO.	DESCRIPTION	UNIT	NO. OF UNITS (ROUNDED)	UNIT COST	ESTIMATED COST
Capital Costs					
1	Mobilization/Demobilization	LS	1	$255,000	$255,000
2	Site Preparation	LS	1	$20,000	$20,000
3	Deflection Wall	SF	9,000	$30	$270,000
4	Turbidity Curtain Installation	LF	3,800	$45	$171,000
5	Debris Removal	AC	8.4	$10,000	$84,000
6	Sediment Removal Activities	CY	41,400	$75	$3,105,000
7	Residuals Cover Layer	CY	800	$35	$28,000
8	Engineered Isolation Cap Placement				
	Sand	CY	7,100	$35	$248,500
	Geotextile	SF	194,000	$0.75	$145,500
	Armor	CY	7,100	$35	$248,500
9	Transportation and Disposal at CDF	CY	46,000	$25	$1,150,000
10	CDF Construction	LS	1	$330,000	$330,000
11	Bathymetric Survey	EA	2	$30,000	$60,000
12	Sheetpile Dock Support	SF	24,000	$30	$720,000
				Subtotal:	$6,835,500
13	Project/ Construction Management (5%)				$341,800
14	Engineering and Administration (10%)				$683,600
15	Contingency (25%)				$1,708,900
				Total Capital Cost:	$9,569,800
Operation and Maintenance (O&M) Costs					
16	Cap Monitoring	LS	1	$45,000	$45,000
				Total Present Worth O&M Costs:	$45,000
				Present Worth Factor (30 years @ 4.5%):	7.74
				Total O&M Cost:	$348,200
				Rounded Total:	**$9.9 M**

Units Key: LS = Lump Sum; LF = Linear Foot; AC = Acre; CY = Cubic Yard; EA = Each; SF = Square Foot.

See assumptions on page 2.

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Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table E-4 - Alternative 4: Partial Removal and Cap Placement

General Comments:

1. This cost estimate has been developed at an accuracy of -30 to +50%, in accordance with USEPA guidance (USEPA, July 2000).
2. Costs are rounded off as appropriate.
3. Costs represent summary of estimated capital cost associated with individual items.
4. Unit costs are in 2010 dollars and estimated from standard estimating guides (e.g. Means Site Work and Landscape Cost Data, vendors, professional judgment and/or experience from other similar projects).
5. These estimates are developed using current and generally accepted engineering cost estimation methods. Note that these estimates are based on assumptions concerning future events and actual costs may be affected by known and unknown risks including, but not limited to, changes in general economic and business conditions, site conditions that were unknown at the time the estimates were performed, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates and such variations may be material. We are not licensed as accountants or securities attorneys and, therefore, make no representations that these costs form an appropriate basis for complying with financial reporting requirements for such costs.

Notes and Assumptions:

1. Mobilization/demobilization includes mobilization and demobilization of labor, equipment, and materials necessary to perform remedial activities. Estimate assumes 5% of capital costs excluding transportation and disposal related costs.
2. Site preparation cost estimate includes labor, equipment, and materials necessary to perform clearing, install temporary erosion and sedimentation controls, construct staging and access areas, and otherwise prepare the site for construction.
3. Deflection wall cost estimate includes the procurement, transportation and labor and equipment for installation of the deflection wall as the upstream component of the resuspension control system. Cost estimate assumes 60-foot long AZ18-700 sheeting sections, extending a maximum of 150 feet from the shoreline for the purpose of this cost estimate. Installation of deflection wall is assumed from barge.
4. Turbidity curtain installation includes procurement, transportation, labor and equipment associated with installation and removal of turbidity curtain and accessories. Turbidity curtains will be utilized to mitigate potential migration of sediment during construction activities. Turbidity curtains are assumed to encompass the remedial footprint and anchored to the shoreline.
5. Debris removal includes all labor, materials, equipment, and services necessary for handling/removing obstacles and debris (e.g., boulders, remnant concrete slabs, etc.) from remediation areas. Assumes offsite disposal of debris.
6. Sediment removal activities includes all labor, materials, equipment, and services necessary to complete excavation of impacted material. Excavated material will be transported via barge to the USACE Pointe Mouillee confined disposal facility (CDF). Removal of impacted material is assumed using conventional construction equipment (e.g., excavators, cranes equipped with clamshell buckets, etc.). Sediment removal thickness for each Remedial Area (RA) are provided below:
   - RA - A = 2.0 feet to accomodate cap
   - RA - B = 3.7 feet
   - RA - C = 5.1 feet
   - RA - D = 4.7 feet
   - RA - E = 2.0 feet to accomodate cap
   - RA - F = 3.8 feet

7. Residual cover layer includes procurement and transportation of material necessary for the placement of residual cover layer. Material placement is assumed using a barge and excavator or crane equipped with a clamshell bucket. The layer will consist of a 6-inch thin lift of clean sand material.

BASF Corporation - North Works
Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table E-4 - Alternative 4: Partial Removal and Cap Placement

Notes and Assumptions (continued):

8. Engineered isolation cap placement includes all labor and materials for the procurement and transportation necessary for the placement of cap materials. Cap material placement is assumed using a barge and excavator or crane equipped with a clamshell bucket. Engineered isolation cap will consist of a 2-foot thick, multi-layer cap comprised of the following components: a 1.0-foot clean isolation sand layer, a geotextile liner, and a 1.0-foot layer of 6-inch D_{50} armor stone (6-inch median stone size). Assumption of armor stone sizing is preliminary and may require modifications following collection of additional data and modeling activities.
9. Transportation and disposal of dredged material assumes all materials will be disposed in the USACE Pointe Mouillee CDF. Transportation and disposal will occur via hopper barge to CDF. Material will be unloaded and placed in CDF. Disposal volume estimate assumes removed in-situ materials bulked by 10%.
10. CDF construction includes all labor, materials, equipment and services necessary to construct a new cell at the USACE Point Mouillee CDF. CDF tipping fee and capping are included in the CDF transportation and disposal cost.
11. Bathymetric survey includes performing an interim and final survey utilizing multi- beam acoustic depth measurement techniques in accordance with the USACE Hydrographic Surveying Engineering Manual (EM 1110-2-1003).
12. Sheetpile dock support wall cost estimate includes the procurement, transportation and labor and equipment for installation of the sheetpile support wall. Cost estimate assumes 60-foot long AZ18-700 sheeting sections supporting the shoreline along the 400 foot excavation boundary. Installation of sheetpile support wall is assumed from barge.
13. A 5% allowance is included for project/construction management and is applied to the sum of itemized subtotal capital costs. This allowance includes costs for legal fees, additional permitting (state or local agencies), obtaining access, negotiations, and/or agency oversight.
14. A 10% allowance is included for engineering and administration support and is applied to the sum of itemized subtotal capital costs.
15. A 25% contingency allowance is included to provide for unforeseen circumstances or variability in estimated areas, volumes, costs, and is applied to the sum of itemized subtotaled capital costs.
16. Operation and monitoring costs assume cap monitoring activities commencing the year following the completion of work, annually for the first five years, then every 3 years until year 20, then every 5 years until year 30. Estimate includes annual bathymetric surveys to verify cap elevations and data review. A discount rate of 4.5% has been selected for the net present worth as compared to 7% recommended by USEPA (USEPA 2000).

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Table E-5 - Alternative 5: Targeted Removal with Cap Placement

ITEM NO.	DESCRIPTION	UNIT	NO. OF UNITS (ROUNDED)	UNIT COST	ESTIMATED COST
Capital Costs					
1	Mobilization/Demobilization	LS	1	$200,000	$200,000
2	Site Preparation	LS	1	$20,000	$20,000
3	Deflection Wall	SF	9,000	$30	$270,000
4	Turbidity Curtain Installation	LF	3,800	$45	$171,000
5	Debris Removal	AC	8.4	$10,000	$84,000
6	Sediment Removal Activities	CY	27,000	$75	$2,025,000
7	Residuals Cover Layer	CY	800	$35	$28,000
8	Engineered Isolation Cap Placement				
	Sand	CY	7,100	$35	$248,500
	Geotextile	SF	194,000	$0.75	$145,500
	Armor	CY	7,100	$35	$248,500
9	Transportation and Disposal at CDF	CY	30,000	$25	$750,000
10	CDF Construction	LS	1	$330,000	$330,000
11	Bathymetric Survey	EA	2	$30,000	$60,000
12	Sheetpile Dock Support	SF	24,000	$30	$720,000
				Subtotal:	$5,300,500
13	Project/ Construction Management (5%)				$265,000
14	Engineering and Administration (10%)				$530,100
15	Contingency (25%)				$1,325,100
				Total Capital Cost:	$7,420,700
Operation and Maintenance (O&M) Costs					
16	Cap Monitoring	LS	1	$45,000	$45,000
				Total Present Worth O&M Costs:	$45,000
				Present Worth Factor (30 years @ 4.5%):	7.74
				Total O&M Cost:	$348,200
				Rounded Total:	**$7.8 M**

Units Key: LS = Lump Sum; LF = Linear Foot; AC = Acre; CY = Cubic Yard; EA = Each; SF = Square Foot.

See assumptions on page 2.

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Interim Measures Design Work Plan - Sediments
Table E-5 - Alternative 5: Targeted Removal with Cap Placement

General Comments:

1. This cost estimate has been developed at an accuracy of -30 to +50%, in accordance with USEPA guidance (USEPA, July 2000).
2. Costs are rounded off as appropriate.
3. Costs represent summary of estimated capital cost associated with individual items.
4. Unit costs are in 2010 dollars and estimated from standard estimating guides (e.g. Means Site Work and Landscape Cost Data, vendors, professional judgment and/or experience from other similar projects).
5. These estimates are developed using current and generally accepted engineering cost estimation methods. Note that these estimates are based on assumptions concerning future events and actual costs may be affected by known and unknown risks including, but not limited to, changes in general economic and business conditions, site conditions that were unknown at the time the estimates were performed, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates and such variations may be material. We are not licensed as accountants or securities attorneys and, therefore, make no representations that these costs form an appropriate basis for complying with financial reporting requirements for such costs.

Notes and Assumptions:

1. Mobilization/demobilization includes mobilization and demobilization of labor, equipment, and materials necessary to perform remedial activities. Estimate assumes 5% of capital costs excluding transportation and disposal related costs.
2. Site preparation cost estimate includes labor, equipment, and materials necessary to perform clearing, install temporary erosion and sedimentation controls, construct staging and access areas, and otherwise prepare the site for construction.
3. Deflection wall cost estimate includes the procurement, transportation and labor and equipment for installation of the deflection wall as the upstream component of the resuspension control system. Cost estimate assumes 60-foot long AZ18-700 sheeting sections, extending a maximum of 150 feet from the shoreline for the purpose of this cost estimate. Installation of deflection wall is assumed from barge.
4. Turbidity curtain installation includes procurement, transportation, labor and equipment associated with installation and removal of turbidity curtain and accessories. Turbidity curtains will be utilized to mitigate potential migration of sediment during construction activities. Turbidity curtains are assumed to encompass the remedial footprint and anchored to the shoreline.
5. Debris removal includes all labor, materials, equipment, and services necessary for handling/removing obstacles and debris (e.g., boulders, remnant concrete slabs, etc.) from remediation areas. Assumes offsite disposal of debris.
6. Sediment removal activities includes all labor, materials, equipment, and services necessary to complete excavation of impacted material. Excavated material will be transported via barge to the USACE Pointe Mouillee confined disposal facility (CDF). Removal of impacted material is assumed using conventional construction equipment (e.g., excavators, cranes equipped with clamshell buckets, etc.). Sediment removal thickness for each Remedial Area (RA) are provided below:
   - RA - B = 3.7 feet
   - RA - C = 5.1 feet
   - RA - D = 4.7 feet
   - RA - F = 3.8 feet
7. Residual Cover layer includes procurement and transportation of material necessary for the placement of residual cover layer. Material placement is assumed using a barge and excavator or crane equipped with a clamshell bucket. The layer will consist of a 6-inch thin lift of clean sand material.

BASF Corporation - North Works
Wyandotte, MI
Interim Measures Design Work Plan - Sediments
Table E-5 - Alternative 5: Targeted Removal with Cap Placement

Notes and Assumptions (continued):

8. Engineered isolation cap placement includes all labor and materials for the procurement and transportation necessary for the placement of cap materials. Cap material placement is assumed using a barge and excavator or crane equipped with a clamshell bucket. Engineered isolation cap will consist of a 2-foot thick, multi-layer cap comprised of the following components: a 1.0-foot clean isolation sand layer, a geotextile liner, and a 1.0-foot layer of 6-inch D_{50} armor stone (6-inch median stone size). Assumption of armor stone sizing is preliminary and may require modifications following collection of additional data and modeling activities.
9. Transportation and disposal of dredged material assumes all materials will be disposed in the USACE Pointe Mouillee CDF. Transportation and disposal will occur via hopper barge to CDF. Material will be unloaded and placed in CDF. Disposal volume estimate assumes removed in-situ materials bulked by 10%.
10. CDF construction includes all labor, materials, equipment and services necessary to construct a new cell at the USACE Pointe Mouillee CDF. CDF tipping fee and capping are included in the CDF transportation and disposal cost.
11. Bathymetric survey includes performing an interim and final survey utilizing multi- beam acoustic depth measurement techniques in accordance with the USACE Hydrographic Surveying Engineering Manual (EM 1110-2-1003).
12. Sheetpile dock support wall cost estimate includes the procurement, transportation and labor and equipment for installation of the sheetpile support wall. Cost estimate assumes 60-foot long AZ18-700 sheeting sections supporting the shoreline along the 400 foot excavation boundary. Installation of sheetpile support wall is assumed from barge.
13. A 5% allowance is included for project/construction management and is applied to the sum of itemized subtotal capital costs. This allowance includes costs for legal fees, additional permitting (state or local agencies), obtaining access, negotiations, and/or agency oversight.
14. A 10% allowance is included for engineering and administration support and is applied to the sum of itemized subtotal capital costs.
15. A 25% contingency allowance is included to provide for unforeseen circumstances or variability in estimated areas, volumes, costs, and is applied to the sum of itemized subtotaled capital costs.
16. Operation and monitoring costs assume cap monitoring activities commencing the year following the completion of work, annually for the first five years, then every 3 years until year 20, then every 5 years until year 30. Estimate includes annual bathymetric surveys to verify cap elevations and data review. A discount rate of 4.5% has been selected for the net present worth as compared to 7% recommended by USEPA (USEPA 2000).

ARCADIS

Figures

CITY: SF DIV/GROUP: IM DB: KERNST LD: PIC: PM: TM: TR:
Project (Project #) B0042929.0019.00020
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LEGEND:

2009 BATHYMETRIC CONTOURS (5 FT)
FEDERAL CHANNEL
REMEDIATION AREA BOUNDARY
SEDIMENT REMOVAL
SEDIMENT REMOVAL WITH RESIDUALS COVER LAYER

SHORELINE CLASSIFICATION:
CONCRETE BULKHEAD
METAL SHEET PILING
RIP-RAP

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009
3. DATA ARE IN NAD83 STATE PLANE MICHIGAN SOUTH

DRAFT FOR FEDERAL AND STATE REVIEW

BASF CORPORATION - NORTH WORKS
WYANDOTTE, MI

INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS

ALTERNATIVE 3

ARCADIS

FIGURE
E-1

CITY: SF DIV/GROUP: IM DB: KERNST LD: PIC: PM: TM: TR:
Project (Project #) B0042929.0019.00020
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LEGEND:

2009 BATHYMETRIC CONTOURS (5 FT)

FEDERAL CHANNEL

REMEDIATION AREA BOUNDARY

ENGINEERED ISOLATION CAP AREA WITH 2-FOOT SEDIMENT REMOVAL

SEDIMENT REMOVAL

SEDIMENT REMOVAL WITH RESIDUALS COVER LAYER

SHORELINE CLASSIFICATION:

CONCRETE BULKHEAD

METAL SHEET PILING

RIP-RAP

NOTES:

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2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009
3. DATA ARE IN NAD83 STATE PLANE MICHIGAN SOUTH

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INTERIM MEASURES DESIGN WORK PLAN - SEDIMENTS

ALTERNATIVE 4

ARCADIS

FIGURE
E-2

CITY: SF DIV/GROUP: IM DB: KERNST LD: PIC: PM: TM: TR:
Project (Project #) B0042929.0019.00020
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LEGEND:

- 2009 BATHYMETRIC CONTOURS (5 FT)
- FEDERAL CHANNEL
- REMEDIATION AREA BOUNDARY
- ENGINEERED ISOLATION CAP AREA
- SEDIMENT REMOVAL
- SEDIMENT REMOVAL WITH RESIDUALS COVER LAYER

SHORELINE CLASSIFICATION:

- CONCRETE BULKHEAD
- METAL SHEET PILING
- RIP-RAP

NOTES:

1. AERIAL IMAGERY COLLECTED IN 2005 AS PART OF THE NATIONAL AGRICULTURE IMAGERY PROGRAM.
2. BASF SITE AERIAL TAKEN ON JUNE 26, 2009
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ALTERNATIVE 5

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FIGURE
E-3